ASSESSMENTS OF THE ROLE OF SELF-CONTROL IN DETERMINING AN INDIVIDUAL'S EATING BEHAVIOUR IN DIFFERENT EATING SCENARIOS

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Abstract

Obesity is an increasing global problem. Although the causes of this condition comprise diverse factors, it is argued that a key contributor is the contemporary food environment. The current food environment constantly exposes individuals to an abundance of food-related signals or 'cues' that encourage consumption. There is a growing body of literature that endeavours to understand individual differences in terms of how people respond to these food cues. Interestingly, research shows that some individuals are more susceptible to the effects of the current food environment than others. One of the key hypotheses to explain such individual differences relates to self-control. While previous research affirms self-control is crucial for keeping homeostatic balance, it remains unknown how self-control moderates energy intake and its primary determinants – portion size and energy density. Thus, the aim of the current doctoral research is to systematically test for the role of self-control in determining individuals' eating behaviour. Specifically, the thesis discusses the role of self-control in influencing an individual's food choice, energy intake, portion size and energy density, in different eating scenarios. In addition, the thesis investigates the possibility of a cognitive training paradigm on moderating an individual's self-control for food choice.

In this thesis, Study 1 tested the consistency across three measures of self-control, that are available in the literature, for predicting an individual's food choices. A total of 116 female participants were tested with the inhibitory control test, an implicit self-control task, and an explicit self-control task, and then these measures were then analysed against each participant's performance on a food choice task. Results from this study revealed that the explicit self-control measure (***i.e.*** Tangney's Brief Self-Control Scale) was the most effective approach for predicting food choice (for a high-calorie food) relative to the other two measures (p = 0.002). In addition, no statistical relationship was observed between the three self-control measures (p > 0.05), suggesting they measure distinct self-control processes.

Study 2 assessed the role of self-control energy intake across diverse food categories (*i.e.*, sweet snack, savoury snack and main meal). A total of 61 female participants, identified as having either high or low self-control (*i.e.* Tangney's Brief Self-Control Scale), were tested for their eating behaviour for the above-mentioned three categories of food. Results from this study showed that self-control by this measure had no direct effect on energy intake across the three food categories ($p > 0.05$). Nevertheless, the results revealed that self-control can moderate the energy intake of a certain food category (*i.e.*, sweet snack: $p = 0.048$; savoury snack： $p < 0.001$). This study suggested that the moderating role of self-control on energy intake differed across food categories (found in both sweet and savoury snack, but not in main meal scenario).

Study 3 tested the specific effect of self-control on the two primary determinants of energy intake – portion size and energy density. A total of 44 female participants, identified as having either high or low food self-control (*i.e.* Food Self-Control Scale), were tested with two high and low-calorie foods in both food choice and consumption tasks. Results from the study revealed that self-control only exerted effects on an individual's food choice based on energy density ($p < 0.05$), but not on portion size ($p > 0.05$). This new finding provided useful insights into the subsequent development of a self-control intervention strategy, which was described in study 4.

Study 4 developed a cognitive training paradigm for self-control and tested its effectiveness on influencing both portion size and energy density judgements for individuals with low self-control (*i.e.* Food Self-Control Scale). The training paradigm was constructed based on a modified implicit association test in conjunction with body images. Results showed that individuals who underwent the training programme had no significant reduction in their portion size nor energy density intake compared to the baseline session ($p > 0.05$). This study indicated that simple cognitive training cannot moderate the effects of self-control on dietary decision-making.

Overall, this doctoral research assessed the role of self-control in determining an individual’s eating behaviour in different eating scenarios. Findings from this project indicated self-control, as a top-down self-control trait, was associated with choices of food energy density, it however did not directly influence portion size. The moderating role of self-control on food choice and energy intake differed across eating scenarios (e.g., present in both sweet and savoury snack consumption, but not in main meal consumption). Overall, this research provided important and novel insights into the role of self-control in regulating eating behaviour via food energy density.

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Table of contents

List of Figures

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

List of Tables

Chapter 1

Chapter 2

Chapter 3

Chapter 4

List of Acronyms

AB	Attentional bias
ANOVA	Univariate analysis of variance
BFCR	Behavioural forced-choice responses
BMI	Body Mass Index
BSCS	Tangney's Brief Self-Control Scale
BWCM	Body weight control motive
CEI	Chips energy intake
CI	Confidence interval
CL	Chips liking
CMH	Cochran-Mantel-Haenszel
CS	Conditioned stimulus
DEBQ	Dutch Eating Behaviour Questionnaire
DEBQ-D	Dutch Eating Behaviour Questionnaire-Disinhibited eating
DEBQ-Em	Dutch Eating Behaviour Questionnaire-Emotional eating
DEBQ-Ex	Dutch Eating Behaviour Questionnaire-External eating
DEBQ-R	Dutch Eating Behaviour Questionnaire-Restrained eating
EC	Evaluative Conditioning
ED	Energy density
EV	Expectancy-value
FA	Fasting
FCQ	Food Choice Scale
FSC	Food self-control scale
HBCS	Hunger before chips session
HBICS	Hunger before ice cream session
HBPS	Hunger before pasta session
HCF	High-calorie food
HEDF	High energy density food
HFSC	High food self-control
IAT	Implicit association task
ICEI	Ice cream energy intake
ICL	Ice cream liking
ISC	Implicit self-control
LCF	Low-calorie food
LEDF	Low energy density food
LFSC	Low food self-control
N-FA	Non-fasting
N.S	Non-significant
NZ	New Zealand
PEI	Pasta energy intake
PL	Pasta liking
PS	Portion sizes
RTs	Reaction times

SCS	Tangney’s Self-Control Scale
SCT	Social Cognitive Theory
SD	Standard deviation
SE	Standard error
SST	Stop-signal task
ST-IAT	Single-target implicit association test
TFEQ	Three Factor Eating Questionnaire
TPB	Planned Behaviour Theory
UCS	Unconditioned stimulus
VAS	Visual Analogue Scale

Chapter 1: Introduction, literature review and objectives

1.1 Introduction

Obesity is a chronic disease that can cause serious health consequences such as Type-II diabetes and cardiomyopathy (Wang et al., 2011). The worldwide prevalence of obesity has dramatically increased from 6% to 15% among females over the last four decades (Jaacks et al., 2019). The obesity epidemic attributes to the combined effects of genetic and environmental factors (Farooqi & O'Rahilly, 2007; Hill & Peters, 1998; Hill, Wyatt, & Melanson, 2000). In recent years, the dramatic changes in the food environment are characterised in serving high energy density food (HEDF) in large portion sizes (Kling, Roe, Keller, & Rolls, 2016; Pourshahidi, Kerr, McCaffrey, & Livingstone, 2014). The rewarding sensory properties of such food stimuli motivate people's approaching behaviour towards them, which drives to overeating (Castellanos et al., 2009; Chen & Bargh, 1999; Cohen & Farley, 2008; Duckworth, Bargh, Garcia, & Chaiken, 2002; Ferguson & Bargh, 2013; Polivy, Herman, & Coelho, 2008). Being exposed to such food stimuli has been identified as a primary driver of homeostatic energy imbalance and weight gain (Kral & Rolls, 2004). An interesting question is why some individuals are more susceptible to overeating than others in such a food environment.

Extensive research has endeavoured to identify factors determining individual differences in eating behaviour (De Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012). One of the key hypotheses is that individuals exhibit different levels of self-control for food temptation (Johnson, Pratt, & Wardle, 2012). Self-control refers to the capability to inhibit impulses in order to attain long-term goals (Baumeister, Vohs, & Tice, 2007). Positive effects of high self-control are evident in academic performance (Duckworth & Seligman, 2005), social relations (Tangney, Baumeister, & Boone, 2004), physical activities (Kinnunen, Suihko, Hankonen, Absetz, & Jallinoja, 2012), and healthy eating (Sproesser, Strohbach, Schupp, & Renner, 2011). Specifically for eating behaviour, individuals with high self-control typically have a higher consumption of fruits and vegetables (Wills, Isasi, Mendoza, & Ainette, 2007) and lower high-fat food intake (Gerrits et al., 2010). By contrast, individuals with low self-control have difficulties inhibiting impulses for instantaneous satisfaction, particularly in circumstances with temptations (Metcalfe & Mischel, 1999). In the current obesogenic environment where food temptations are common, self-control is hypothesised to be an important factor in determining individual differences in eating behaviour.

Previous literature has confirmed the importance of self-control in keeping homeostatic balance. However, there is little understanding of the effect of self-control on energy intake and its primary determinants – portion size and energy density. Thus, further research is required to understand the role of self-control in determining an individual's eating behaviour in different eating scenarios. Such understanding of the mechanism of inter-individual difference in eating behaviour could be valuable for constructing intervention strategies, which could potentially help individuals to achieve better appetite control and weight regulation.

This introductory chapter discusses a number of key concepts in the field of self-control and eating behaviour.

1.2 Definition of self-control

Self-control plays an important role in people's life. Research on self-control encompasses a wide range of disciplines and is therefore conceptualised in many ways (De Ridder et al., 2012; Duckworth & Kern, 2011). Tangney et al. (2004) proposed self-control is a trait, developed a general trait self-control measure based on a comprehensive review on measuring self-control in the previous study. Fishbach and Shah (2006) proposed that self-control process involved in behavioural responses, they developed an approach avoidance task that represents the tendency of approaching healthy-eating cues (***e.g.***, lean figure) or avoiding tempting food cues (***e.g.***, high energy density food). Logan (1994) developed a stop-signal paradigm that involved in the cognitive process which aims to assess the ability of the subject to identify conflicts and stop a habitual or dominant behaviour based on a signal, namely the ability of response inhibition. In this doctoral research, self-control is defined as a trait that refers to the capability to inhibit impulses in order to attain long-term goals (Baumeister, Vohs, et al., 2007).

1.3 Theories of self-control

Since psychology began to pay attention to self-control field, researchers have put forward many theoretical models and corresponding self-control measure to explain the mechanism of self-control that consists of the strength model, two-stage model, dual-motive conflicts model, impulsive-reflective model, proactive-reactive model, top-down and bottom-up process (Table 1.1). These theories facilitate greater insights into various behavioural domains. These theories will be clarified and explained with examples in the following section.

Table 1.1 - Summary of self-control theories in this thesis

Models name and explanation	Examples	Methods developed	Characteristics
The strength model: the process of implementing self-control depends on limited energy resources (Baumeister, Muraven, & Tice, 2000).	Self-control as a person's muscles will feel tired after a certain time of exercise.	State self-control: ego-depletion; unstable. Trait self-control: Tangney's Self-Control Scale; stable.	-Energy-based.
Two-stage model: stage 1, individuals need to be able to identify whether the temptation they face will result in self-control conflicts. If conflicts are identified, they will enter the next stage of the control process; otherwise, they will indulge in the temptations. Stage 2 is solving self-control conflict stage. Whether an individual can successfully resist temptation depends on an effective self-control strategy is successfully adopted (resisting the temptation), or it leads to self-control failure (indulging in temptation) (Myrseth & Fishbach, 2009).	Restrained and non-restrained eaters make food choice decision in the front of both high (*e.g.* chocolate) and low energy density of food (*e.g.* apple)	N/A	-Process-oriented. -Stage 1 and 2 explain the reason to cause self-control failure in each stage. -Coping strategy is conscious conflict-inhibiting behaviour after the conflict emerged.
Dual-motive model: Conflicts of self-control (such as delay gratification) represent a conflict between two types of motivators: to obtain a smaller, instant reward or to pursue a larger, long-term reward (Fujita, 2011).	High and low self-control individuals make food choice decision in the front of both high (*e.g.* sweet) and low energy density of food (*e.g.* fruits)	N/A	-External cues-oriented -Proactive coping strategy.

Models name and explanation	Examples	Methods developed	Characteristics
Impulsive-reflective model: "also called hot-cool system". The reflective system is cognitive, well-considered, slow and prudent. The main function of reflective system is to lead the goal-oriented behaviour and make the individual more rational (Ayduk, Mischel, & Downey, 2002). Impulsive system is emotional, impulsive, fast and unplanned, individual gains a pleasure experience through instant gratification without rational thinking (Patrick, Chun, & MacInnis, 2009).	Reflective system as an angel. Impulsive system as an evil.	Explicit method: Tangney's Brief Self-Control Scale. Implicit method: implicit association task.	-Internal system.
Proactive-reactive control model: Proactive control is a goal-driven control that depends on the anticipation and prevention of conflicts before it arises, while reactive control depends on the recognition and resolve of conflicts after it begins (Braver, 2012).	Proactive control processes are to prevent conflict. Reactive control processes are to return the individual to the goal.	Stop-signal task	-Cognitive control oriented. -Prevention and resolve coping strategies for self-control conflicts.
Top-down and bottom-up process: Tempting high energy density food (HEDF) automatically triggering a bottom-up food reward process, which drives individuals' attention to approach them (van Koningsbruggen, Veling, Stroebe, & Aarts, 2017). In a top-down impulse control processes, individuals who proactively control their behaviour refer to an earlier formed goal criteria (*i.e.* weight management goals) (Nigg, 2017; Rauss, Schwartz, & Pourtois, 2011).	Bottom-up processes cause the shift of unconscious attention towards relevant food cues. Top-down control processes involved in a conscious way that direct attention to the goal-related food cue.	N/A	-More comprehensive models (have other models' characteristics). -Involved other aspects such as visual processing.

1.3.1 The strength model

The strength model theory was proposed by Baumeister, Heatherton, and Tice (1994) based on reviewing a large number of previous studies. The theory holds that the process of implementing self-control depends on limited energy resources (Baumeister et al., 2000). Just as a person's muscles will feel tired after a certain time of exercise, self-control behaviour will lead to the depletion of psychological resources (***i.e.*** blood glucose level), which in turn affect the self-control behaviour in the short term (Baumeister, Bratslavsky, Muraven, & Tice, 1998). This phenomenon is called “ego-depletion” (Baumeister, Vohs, et al., 2007).

The researchers further pointed out that this “psychological resource” is similar to the blood glucose level, and only if the individual’s blood glucose is maintained at a certain level can it be ensured to use enough psychological resources to conduct self-control operations. Conversely, if the previous self-control behaviour consumes a lot of blood glucose, there will be self-depletion effects (Gailliot & Baumeister, 2007; Gailliot et al., 2007). If blood glucose is replenished in time, the ego-depletion effect can be effectively eliminated (Gailliot et al., 2007).

The previous meta-analysis about ego-depletion confirmed the existence of this effect (Hagger, Wood, Stiff, & Chatzisarantis, 2010). However, some researchers have questioned the strength model theory, they suggest that the blood glucose level should not be simply viewed as energy resources of self-control (Molden et al., 2012). The criticisms of ego depletion effect have been questioned on conceptual grounds (Lurquin & Miyake, 2017) and such effect fails to be replicated (Hagger et al., 2016). Inzlicht and Schmeichel (2012) proposed a process model of ego-depletion based on extensive previous studies. They considered that the implementation of self-control in the early phase would cause the transfer of motivation and attention in the later phase, and then affect the self-control behaviours in the later phase (Inzlicht & Schmeichel, 2012). This means changes in motivation and attention, rather than the change of blood glucose levels, have led to the emergence of self-depletion effects (Hagger et al., 2010; Inzlicht & Schmeichel, 2012).

Based on the strength model theory, an individual's self-control is unstable (Baumeister, Vohs, et al., 2007). Self-control can be depleted through task operations and it can also be improved through replenishment of energy or self-control training (Inzlicht & Schmeichel, 2012). Based on this view, Tangney et al. (2004) distinguished two types of self-control: state self-control and trait self-control. State self-control will change with the individual's emotional state, the surrounding environment and the physiological conditions such as ego-depletion effects (Ackerman, Goldstein, Shapiro, & Bargh, 2009; Hagger et al., 2010; Salmon, Adriaanse, De Vet, Fennis, & De Ridder, 2014). In contrast, trait self-control is an individual's relatively stable personality tendency that does not change with time and context (Gillebaart, Schneider, & De Ridder, 2016; Moffitt et al., 2011; Wang et al., 2015).

1.3.2 Two-stage model

Myrseth and Fishbach (2009) suggest that successful self-control relies on the individual's efforts in two stages: identifying conflict stage and invoking effective self-control coping strategies stage. This theoretical model is based on the conflict monitoring theory in cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001). In the first stage, individuals need to be able to identify whether the temptation they face will result in self-control conflicts (contradictions with long-term goals). If conflicts are identified, they will enter the second stage of the control process; otherwise, they will indulge in the temptations. The second stage is solving self-control conflict stage. Whether an individual can successfully resist temptation depends on an effective self-control strategy is successfully adopted (resisting the temptation), or it leads to self-control failure (indulging in temptation). For instance, restrained eating is defined as the intentional and sustained restriction of caloric intake for the purpose of weight loss or weight maintenance (Herman & Mack, 1975). When restrained and non-restrained eaters make food choice decision in the front of both high (*e.g.* chocolate) and low energy density of food (*e.g.* apple), restrained eaters firstly identify high energy density food as a threat due to self-control conflicts arise in the current food context (contradictions with their weight management goals). Then some restrained eaters endeavour to solve this conflict and act in line with their weight management goals, they successfully resist the temptation of delicious high energy density food (HEDF) (Scott, Nowlis, Mandel, & Morales, 2008). Some restrained eaters consider that having smaller quantities of high energy density food is "acceptable" (Coelho do Vale, Pieters, & Zeelenberg, 2008). This has been found that a restrained eater had a higher calories intake in a small packaged format (Scott et al., 2008). Therefore, this ineffective coping strategy adopted by these restrained eaters fails to solve self-control conflicts that lead to self-control failure (indulging in palatable high energy density food). However, due to no existence of weight control goals in mind, non-restrained eaters fail to identify high energy density food as a threat in this food context. Non-restrained eaters indulge in palatable high energy density food, which contributes to their unsuccessful weight management (Scott et al., 2008).

1.3.3 Dual-motive conflicts model

The dual-motive conflicts model suggests that the process of self-control can be seen as the process of resolving dual-motive conflicts between two different motives (Fujita, 2011). Conflicts of self-control (such as delay gratification) represent a conflict between two types of motivators: to obtain a smaller, instant reward or to pursue a larger, long-term reward. The dual-motive conflicts model suggests that successful self-control consists of proactively adopting strategies to avoid or reduce the possibility of conflict, rather than adopting conscious conflict-inhibiting behaviour after the conflict has emerged (Fujita, 2011). For instance, when high and low self-control individuals make food choice decision in front of both high (*e.g.* sweet) and low energy density of food (*e.g.* fruits). Such food context involved a conflict between two types of motivators: to obtain a smaller, instantaneous satisfaction (pleasure associated with consuming high energy density food) or to pursue a bigger, long-term goal (consuming low energy density food for successful weight management) (Fujita, 2011). High and low self-control individuals differ in their motives and propensity to exhibit different levels of self-control in food choice decision (Hofmann, Baumeister, Förster, & Vohs, 2012). High self-control individuals made healthiness judgments that promote healthier food choices compared to low self-control individuals (Davis, Haws, & Redden, 2013). High food self-control individuals had proactively avoided foods with a high energy density and selected more low energy density food. This is supported by Hofmann, Baumeister, et al. (2012), who found that individuals with high self-control had a less motivational conflict and are better at avoiding temptations. The tendency to decrease intake of high energy density foods and select more low energy density food contributed to successful weight management for high self-control individuals (Haws, Davis, & Dholakia, 2016a; Haws, Davis, & Dholakia, 2016b). However, low self-control individuals do not have weight control goals when they make food choice decision, food taste rather than food heathenness has been identified as a primary driver for low self-control individuals (Sullivan, Hutcherson, Harris, & Rangel, 2015). High energy density food brings an eating impulse for low self-control individuals, unsuccessful self-control is more likely to occur for low self-control individuals because they are attracted to instantaneous satisfaction due to the reward of high energy density food (HEDF) (Gillebaart & Ridder, 2015).

1.3.4 Proactive-reactive control model

Braver (2012) proposed the Dual Mechanisms of Control Framework (DMC) that distinguish the proactive and reactive control in the cognitive control process. Specifically, proactive control makes the target-related information remaining proactive in the working memory. It is a proactive state that the individual maintains before the presence of the target information. It is an “early selection” mechanism, and the reactive control is a corresponding response when the individual detects the conflicts, it is a kind of "later correction" (Botvinick & Braver, 2015; Braver, 2012; Braver, Paxton, Locke, & Barch, 2009). Proactive control is a goal-driven control that depends on the anticipation and prevention of conflicts before it arises, while reactive control depends on the recognition and resolve of conflicts after it begins (Braver, 2012). For instance, inhibitory control was assessed by the Stop-Signal Task (SST) (Verbruggen, Logan, & Stevens, 2008). Participants wore a pair of headphones and fixated their gaze on a circle. In each “Go” trial, the participant was presented with a horizontal arrow and asked to press either “Left” or “Right” options to indicate the direction of the arrow. This “Go” trial involved proactive control, participants have anticipations about the direction of the arrow. In each “Stop” trial (25% of total trials), indicated by a beep sound, the participant was required not to respond to the presented stimulus. This “Stop” trial involved reactive control. Participants recognise the beep sound and make no actions on the direction of the arrow (Logan, Schachar, & Tannock, 1997). In eating domain, proactive control might involve different strategies to prevent food temptation, which could be automatic or habitual behaviours (avoiding high energy density food options), but could also be intentional actions (filling up on low energy density snacks to prevent hunger-driven snacking later). Reactive control might be activated by external cues such as peer pressure, chatting with friends in a restaurant about someone’s fat figure and questions about an unhealthy diet that person had. Such a conversation may return them to the weight management goal. Reactive control might involve the coping strategy to avoid high energy density food option (***e.g.*** dessert) in a restaurant (Braver, 2012; Nigg, 2017).

1.3.5 Impulsive-reflective model

Strack and Deutsch (2004) proposed an impulsive-reflective model also called the “hot-cool system”, they considered the implementation process of self-control contained two systems: impulsive system and reflective system. The reflective system is cognitive, well-considered, slow and prudent. The main function of the reflective system is to lead the goal-oriented behaviour and make the individual more rational (Ayduk et al., 2002).

On the contrary, the impulsive system is emotional, impulsive, fast and unplanned, individual gains a pleasant experience through instant gratification without rational thinking (Patrick et al., 2009). It makes the person more emotional when making decisions (Metcalfe & Mischel, 1999). The two systems operate according to different principles. The reflective system follows the "reasonable" principle, and the impulsive system follows the "comfort" principle to determine individuals' behaviours (De Ridder et al., 2012). Specifically, the reflective system is responsible for information processing in the cognitive control process, so that individuals can avoid conflicts with information unrelated to long-term goals and make optimal decisions; impulsive systems are responsible for processing impulses, desires, emotions, and other information to meet the individual's immediate pleasure (Casey et al., 2011). For instance, when individuals make food choice decision in front of both high (*e.g.* dessert) and low (*e.g.* apple) energy density of the food. The reflective system as an angel, sounds will come up from one side: "do not eat a dessert, it is going to put weight on you, eat an apple, it's good for your health". However, the impulsive system as evil, sounds will come up from the other side: "go for that dessert, it is very tasty". Previous studies have indicated that self-control process involves the reflective (*i.e.* explicit) and impulsive (*i.e.* implicit) systems (Hofmann, Friese, & Strack, 2009; Keatley, Allom, & Mullan, 2017; Strack & Deutsch, 2004). Therefore, self-control is suggested to be measured with both explicit (*i.e.* Tangney's Brief Self-Control Scale) and implicit (*i.e.* implicit association task) methods (De Ridder et al., 2012; Duckworth & Kern, 2011). The following section (section 1.5) discusses a number of key concepts of explicit and implicit methods for measuring self-control.

1.3.6 Top-down and bottom-up processes

Prior research proposed that behaviour related to the pursuit of multiple goals may be guided by these two distinct processes (Kruglanski et al., 2002), involving the top-down (*i.e.* deliberate) impulse control and the bottom-up (*i.e.* impulsive) food reward processes (Hofmann et al., 2009). Tempting high energy density food (HEDF) automatically triggering a bottom-up food reward process, which drives individuals' attention to approach them (van Koningsbruggen et al., 2017). In a top-down impulse control process, individuals who proactively control their behaviour refer to earlier formed goal criteria (***i.e.*** weight management goals) and select which behaviours can help them meet their present goal criteria (***i.e.*** avoid tempting food) (Nigg, 2017; Rauss et al., 2011). These two processes often work together to determine individuals' responses towards the given food context. Hofmann et al. (2009) suggest that one of these dual processes is involved or both processes can be activated concurrently to determine individuals' behaviour, which is also dependent on internal and external factors in the given context (De Ridder et al., 2012; Herman & Mack, 1975; Kemps, Tiggemann, & Hollitt, 2014; Wansink, 2006; Wardle, 1987). For example, bottom-up food reward process is activated all the time, while top-down impulse control process may be involved or not involved in the same food context (Andrade, May, & Kavanagh, 2008; Connor, Egeth, & Yantis, 2004; Higgs, Dolmans, Humphreys, & Rutters, 2015). If top-down impulse control process is successfully activated, effectively resisting the impulse for instantaneous satisfaction can be performed in order to achieve long-term weight management goals, especially among high self-control individuals (Fishbach & Shah, 2006; Hofmann, Friese, & Wiers, 2008; Kroese, Adriaanse, Evers, & De Ridder, 2011). If top-down impulse control process is disengaged in regulating the eating impulse, turning off top-down impulse control process may result in an approaching behaviour for meeting instantaneous satisfaction, in particular among low self-control individuals (Gillebaart & Ridder, 2015; Haws & Redden, 2013; Hofmann et al., 2009). Such interaction between bottom-up food reward process and top-down impulse control process not only determines food intake during the consumption stage but also occurs in visual attention during the meal-planning stage. The bottom-up food reward process is motivated by the properties of food cues that cause the shift of unconscious attention towards relevant food cues during the initial phases of visual processing (Connor et al., 2004). Therefore, the bottom-up process seems to generate a robust effect at the initial phase of visual attention (Junghans, Hooge, Maas, Evers, & De Ridder, 2015). Top-down impulse control processes involved in a conscious way that direct attention to the goal-related food cues (Kean & Lambert, 2003). Hence, the top-down process is more likely to produce a great influence during the later phases of visual processing (Junghans et al., 2015).

1.3.7 The difference and similarity of self-control theories

As shown in Table 1.1, the strength model suggests that implementing self-control is based on limited energy resources (Baumeister et al., 2000). These authors described self-control with an analogy of muscles, which can become tired after prolonged exercises (Baumeister et al., 2000). According to this model, Tangney, Baumeister, and Boone (2004) developed a measurement of general trait self-control scale, referred to as the Tangney's Self-Control Scale.

In contrast, the impulsive-reflective model focuses on the internal system of individuals (*i.e.*, implicit reflective system: an angel; explicit, impulsive system: an evil). Specifically, Strack and Deutsch (2004) suggest that self-control is guided by the impulsive system (*i.e.*, gain pleasure experience through instant gratification without rational thinking) and the reflective system (*i.e.,* rational thinking leads to goal-oriented behaviour). Later studies demonstrated that self-control process involves both of the reflective (*i.e.* explicit) and impulsive (*i.e.* implicit) systems (Hofmann, Friese, & Strack, 2009; Keatley et al., 2017; Strack & Deutsch, 2004). As a result, self-control is recommended to be measured with both explicit (*i.e.* Tangney's Brief Self-Control Scale) and implicit (*i.e.* implicit association task) methods (De Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012; Duckworth & Kern, 2011).

Dual-motive conflicts model, on the other hand, focuses on the effect of external cues on resolving internal conflicts. It suggests that a process of self-control can be seen as the process of resolving dual-motive conflicts between two types of motivators, either to obtain a smaller, instant reward or to pursue a larger, long-term reward (Fujita, 2011).

For instance, individuals with high food self-control can proactively avoid foods with a high energy density and select low energy density food, contributing to successful weight management (Haws, Davis, & Dholakia, 2016a; Haws, Davis, & Dholakia, 2016b). The dual-motive conflicts model targets on the self-control conflicts caused by the motivators from external cues (high vs low energy density food), this model also involves a proactive strategy to solve this conflict.

Differently, the two-stage model, proposed by Myrseth and Fishbach (2009), claims that the individual's self-control efforts undergo two stages: identifying conflict stage and invoking self-control coping strategies stage. Two-stage model is process-oriented and explains self-control failures according to each stage. The coping strategy of this model is to adopt conscious conflict-inhibiting behaviour after the conflict emerged rather than having a proactive control. This is directly different from dual-motive conflicts, which involves proactive coping strategy. An example of the two-stage model is that restrained eaters firstly identify high energy density food as a threat due to self-control conflicts arise in the current food context (contradictions with their weight management goals) (Scott, Nowlis, Mandel, & Morales, 2008).

The proactive-reactive control model suggests that proactive control is to prevent conflict, while reactive control is to resolve conflicts after it begins, such as re-direct the individual to the goal (Braver, 2012). The Stop-Signal Task (SST) represents the proactive-reactive control model (Verbruggen et al., 2008). The "Go" trials require proactive control, where participants need to anticipate the direction of the arrow. On the other hand, the "Stop" trials require reactive control, participants recognise the stop signal and resist to actions (Logan et al., 1997). In the eating domain, proactive control may involve different strategies to prevent food temptation, which can be habitual behaviours (avoiding high energy density food options), but also can be intentional actions (filling up on low energy density snacks to prevent hunger-driven snacking later). Both proactive control and reactive control belong to top-down processes.

Finally, a broader model is based on top-down and bottom-up processes. Specifically, top-down processes reflect the characteristics of a reflective system, which guides goal-oriented behaviour, bottom-up processes reflect the characteristics of an impulsive system, which leads individuals to meet their immediate pleasure (Fishbach & Shah, 2006; Hofmann, Friese, & Wiers, 2008; Kroese, Adriaanse, Evers, & De Ridder, 2011). Moreover, this model based on top-down and bottom-up processes, it also considers the motivators from external cues (high vs low energy density food) similar to the dual-motive conflicts model. Additionally, the top-down and bottom-up model also has some similar features to the Two-stage model, as it is also a process-oriented. Top-down and the bottom-up processes not only interact during the consumption stage but also occur in visual attention during the meal-planning stage (Connor, Egeth, & Yantis, 2004).

1.4 Different measurements of self-control

The definition of self-control directly determines how to measure self-control. As mentioned earlier, self-control involves many different research-oriented concepts such as impulsivity and delay of gratification (Moffitt et al., 2011). Therefore, the measurements of self-control also show diversity. According to the existing literature and a recent meta-analysis (Duckworth & Kern, 2011), the type of self-control measures consists of behavioural, explicit and implicit methods.

1.4.1 Behavioural measure of trait self-control

Different behavioural paradigms were developed to measure subjects' self-control on cognitive control, emotional regulation and behavioural inhibition. The paradigm commonly used in cognitive control is the stop-signal task (Logan, 1994), which aims to assess the ability of the subject to identify conflicts and stop a habitual or dominant behaviour based on a signal, namely the ability of response inhibition. For instance, the stop-signal task (SST) involved 'go' and 'stop' task (Verbruggen et al., 2008). A fixation circle is shown first in the centre of the screen, participants are shown an arrow that either directs right or left in this circle. For the 'go' task, participants are instructed to press the left corresponding key if the arrow shows to the left direction and press the right corresponding key if the arrow shows in the right direction. For the 'stop' task (takes up 25% of total trials), participants are asked to inhibit this response after a sound of "beep" came up (Logan et al., 1997).

1.4.2 Explicit measure of general trait self-control

Psychology studies have suggested that self-control emerges as two distinguishable processes, involving the reflective (*i.e.* explicit) and impulsive (*i.e.* implicit) systems (Hofmann et al., 2009; Keatley et al., 2017; Strack & Deutsch, 2004). Therefore, self-control is recommended to be assessed with both explicit and implicit methods (De Ridder et al., 2012; Duckworth & Kern, 2011). The explicit measures are mainly used to assess the individual's relatively stable self-control ability or tendency, which represents the level of trait self-control (Duckworth & Kern, 2011).

Tangney and colleagues compiled the trait self-control scale that consists of 36 statements which are divided into five dimensions that include general self-discipline, impulse control, health habits, work or learning performance and reliability (Tangney et al., 2004). A short version of this scale has a total of 13 questions that contain two dimensions: restraint and impulsivity (Maloney, Grawitch, & Barber, 2012). A recent study confirmed the uni-dimensionality of the short version of the self-control scale, and it is considered feasible to use the total score of the scale to assess the individual's self-control level (Lindner, Nagy, & Retelsdorf, 2015). Tangney's Brief Self-Control Scale (BSCS) is regarded as a validated and common self-reported measure (De Ridder et al., 2012; Maloney et al., 2012; Tangney et al., 2004).

1.4.3 Implicit measure of general trait self-control

Self-control has been described as conscious and non-conscious processes, which highlight the role of reflective and impulsive systems based on the dual-process models (Hofmann et al., 2009; Strack & Deutsch, 2004). Recently, studies have shown that deliberative self-control process may be more likely coupled with an unconscious operation (Fishbach, Friedman, & Kruglanski, 2003). For instance, the diet goal of successful restrained eaters is expected to be unconsciously activated once they see high energy density food (HEDF) (Büttner, Florack, & Serfas, 2014). Self-control process is likely to be automatically triggered by tempting objects for these successful self-controllers (Fishbach et al., 2003). An implicit measure of self-control (Implicit association task) was first developed by Keatley, Allom, and Mullan (2017), such a method has been only applied to assess trait of self-control in aggressive tendencies. With the classic IAT, participants are asked to pair attributes (***e.g.*** "self-control" or "impulsivity") and target (***e.g.*** "self" or "other") categories, to assess the associative strength between these concepts (Greenwald et al., 1998). The IAT measures a participant's beliefs about their self-control, they associate themselves with the word "self-control" or "impulsivity". Later, Karpinski (2004) found that the mental representation of "self" could change as a function of the representation of "other", and thus developed a single-target implicit association test (ST-IAT). This modified method has been recommended for its high reliability and validity (Bluemke & Friese, 2008).

1.5 Different measurements of eating behaviour in self-control research

A key point for an effective eating behaviour measure in self-control related research is that participants ought to recognise the conflicts to be involved with the usage of self-control. Some self-control related studies measure eating behaviour using a healthy (virtue) and unhealthy (vice) food choice methodology. Participants were presented with a series of food choices (consist of both healthy and unhealthy food items), they were instructed to select the most preferred food choice (Haws & Liu, 2016; Liu, Haws, Lamberton, Campbell, & Fitzsimons, 2015). Such a method usually involves food images or real food choice settings. Food choice normally happened during the meal planning stage. Other methods applied to measure eating behaviour in self-control related research is food consumption. Participants were asked to consume the food ***ad libitum*** (Haynes, Kemps, & Moffitt, 2016; Kirk & Logue, 1997). Food consumption measure reflects the intake of certain foods during the consumption stage. Previous studies examined the relationship between self-control and eating behaviour (***i.e.*** virtues and vices food choices, and real food consumption) (Haws et al., 2016a; Haws et al., 2016b). Findings from these two research vice and virtue food choice scenarios can perform better than other eating behaviour measures (*i.e.* vice food consumption) to capture an individual's difference in self-control conflict (Haws et al., 2016a; Haws et al., 2016b). One of the possible explanations may be real food consumption measure involves more influences from external factors (*i.e.* sensory attributes and repetitive consumption) than food choice measure.

1.5.1 Food choice measures

Food choice refers to the process by which people measure the value of all attributes of food according to their experience, needs, motivations and perceptions, then choose the relatively most satisfying food options (Sobal & Bisogni, 2009). Feeding is people's instinctive behaviour and is essential to human survival and development (Peters, Wyatt, Donahoo, & Hill, 2002; Van Dyke & Drinkwater, 2014). In the past, food resources were scarce, and human beings were faced with the greatest difficulty to get enough food for their daily life (Godfray et al., 2010). With the continuous progress of human civilisation and the development of science and technology, in today's rich material life, a wide variety of food are oversupplied (Jellil, Woolley, & Rahimifard, 2018). For instance, drastic changes in the food environment are manifested by an increase of portion sizes (PS) and energy densities (ED) (Duffey & Popkin, 2011). People's focus is no longer to look everywhere for food but to make food choice decisions in front of many food options (Devine, Sobal, Bisogni, & Connors, 1999).

After a long period of extreme scarcity of food resources, ensuring adequate calories is the priority (Godfray et al., 2010). Therefore, even when exposed to a wide range of food, people instinctively choose high fat and high-calorie food to ensure enough life energy (Popkin, 2009). This leads to a range of diet-related diseases such as obesity, type II diabetes, high blood pressure, cardiovascular disease, higher cholesterol, acquired heart disease, and even certain cancers (Stein & Colditz, 2004; Wang, McPherson, Marsh, Gortmaker, & Brown, 2011).

Food choice measure in self-control related research allows individuals to make decisions between two choices, which involve trade-offs between instantaneous satisfaction and long-term goals. Shiv and Fedorikhin (1999) employed a trade-off between cake and salad based on food perception. Other classic trade-offs employed in the food-related research consist of sweet snacks versus fruits (***e.g.*** cookies and apples) (Gal & Liu, 2011; Garg, Wansink, & Inman, 2007; Liu et al., 2015), savoury food versus vegetable (***e.g.*** fries and carrots) (Liu et al., 2015), healthy bar versus unhealthy bar (***e.g.*** sweets versus granola bars) (McFerran, Dahl, Fitzsimons, & Morales, 2009), to name just a few. These high and low energy density food stimuli are usually selected based on the preliminary test or previous studies. The notion of these choice settings in self-control related research is that most individuals would perceive one of the choices as instantaneous satisfaction, impulsive or a vice choice and the other as the choice as long-term goals oriented, controlled, or virtuous behaviour (Haws & Liu, 2016; Liu et al., 2015).

1.5.2 Food consumption measures

Another eating behaviour measure used in self-control related research is food intake. This measure quantifies the total energy intake of the food consumed (Kling et al., 2016) or the amount of food consumed (Haws et al., 2016a). The total energy intake is determined by the portion size (PS) and energy density (ED) of food (Kling et al., 2016). The increase in PS and high ED food in the marketplace has been identified as the main contributors of homeostatic energy imbalance and weight gain (Johnson, Mander, Jones, Emmett, & Jebb, 2008; Pourshahidi et al., 2014). PS refers to the quantity of food planned or consumed by a person in a single consumption occasion (Pourshahidi et al., 2014). The increase in PS promoting increased energy intake is evident across different food types, populations and eating scenarios (Zlatevska, Dubelaar, & Holden, 2014). Specifically, individuals with augmentation of portion size information showed increased energy intake (Spanos, Kenda, & Vartanian, 2015; Versluis, Papies, & Marchiori, 2015). The food energy density refers to the energy content per unit weight (Kcal/g or Kcal/100g) (Kral & Rolls, 2004). The ED of food has been suggested to have robust effects on energy intake across different populations (Kling et al., 2016). For instance, previous studies assessed the effect of ED on food intake in lean and obese females by manipulating the fat contents (low, medium, and high) of the food stimuli. Findings suggested that the ED of food, rather than the nutrient content (fat levels), affected females' (both lean and obese) energy intake (Bell, Castellanos, Pelkman, Thorwart, & Rolls, 1998; Bell & Rolls, 2001). Other research on children's diets also showed that a 40% increase in the energy density of the staple food in a meal can increase children's energy intake by an average of 17% (Fisher, Liu, Birch, & Rolls, 2007). This evidence suggests that individuals presented with a higher energy density of food have a greater energy intake (Kral & Rolls, 2004).

Food consumption also quantifies the amount of food consumed (Haws et al., 2016a). The concept for this measure is that low self-control individuals would have a higher amount of high energy density food (HEDF) consumption (Haws et al., 2016a). Extensive research has achieved consensus that having small amounts of food indicates high self-control as opposed to eating a large amount of a high energy density food (HEDF) (De Ridder et al., 2012; Wang et al., 2015; Will Crescioni et al., 2011). Such food setting in self-control related research only involved high energy density food (HEDF) reflects the ability of individuals on inhibiting unhealthy food consumption. These high energy density food (HEDF) stimuli used in the food-related research consist of sweet snacks (***e.g.***, dessert, candies, cookies) and savoury food (***e.g.*** chips) (Dewitte, Bruyneel, & Geyskens, 2009; Haynes et al., 2016; Zhang, Huang, & Broniarczyk, 2010).

1.6 Self-control and food-related behaviour

An increased intake of high-calorie foods is one of the main causes of homeostatic imbalance, which can lead to weight gain (Blundell & Finlayson, 2004). People vary greatly in terms of resistance to excessive food consumption. Much research has been done to underpin facets determining individual differences in eating behaviour, one of the hypotheses is related to self-control. To date, the effectiveness between these measures relating to self-control – explicit, implicit self-control, and inhibitory control – are yet to be examined, particularly in the context of food choice. Therefore, more research is needed to pinpoint the most effective approach to assess self-control in the context of food choices.

1.6.1 Explicit measure of general trait self-control and food-related behaviour

Prior studies that have assessed the effect of explicit self-control on food consumption have observed conflicting findings. Some studies revealed that explicit self-control has no influence on potato chips intake (Friese & Hofmann, 2009), chocolate consumption (Wang et al., 2015), snack intake (Haynes, Kemps, Moffitt, & Mohr, 2014), amount of cookies eaten (Hagger et al., 2013) and sweet pastry consumption frequency (Robinson, Otten, & Hermans, 2016). However, other studies indicated that explicit self-control was significantly related to snack energy intake (Haynes et al., 2016), healthy food consumption (Giese et al., 2015), an unhealthy snack eaten (Adriaanse, Kroese, Gillebaart, & De Ridder, 2014) and sugar-sweetened soda consumption frequency (Robinson et al., 2016). Therefore, these inconsistent findings need further validation on the effect of explicit self-control in eating behaviours.

Not only the direct effect of general trait self-control was assessed on food consumption, but the moderating effect of explicit self-control was also examined in eating behaviour. The previous study found the moderating role of self-control on the variety effects of food consumption, high self-control individuals had less desire for food and decreased food intake in the presence of multi-foods (Haws & Redden, 2013). Other study found that the moderating role of self-control on the relationship between purchase tendency and snack consumption, low self-control individuals are more susceptible to the relationship between purchase tendency and snack consumption (Honkanen, Olsen, Verplanken, & Tuu, 2012). Take the second study as an example, moderation analysis was used to assess the interaction effect between purchase tendency (independent variable) and self-control (continuous moderator) on snack consumption (dependent variable). Moderation analysis was carried out at one standard deviation above (+1 SD) and below (-1 SD) the mean value of the moderator (self-control). The groups of the moderator were coded as +1 SD (high self-control group) and -1 SD (low self-control group), the computed slopes were created for these two groups (Muller, Judd, & Yzerbyt, 2005). The moderation analysis is similar to the median split, moderation analysis is based on a continuous variable, the median split is to split continuous variable into categorical data (Hayes, 2013).

1.6.2 Implicit measure of general trait self-control and food-related behaviour

The implicit measure of self-control (Implicit association task) was first developed by Keatley et al. (2017), such a method has been only applied to assess trait of self-control in aggressive tendencies. Therefore, implicit self-control is yet to be examined, particularly in the context of food choice. There is a need to apply implicit self-control measure in assessing eating behaviour in order to attain a better understanding of the relationship between implicit self-control and food choice.

1.6.3 Inhibitory control (Stop signal tasks) and food-related behaviour

Inhibitory control has also been suggested to be a critical factor in regulating behaviour (Barkley, 1997). This trait, referring to the ability to inhibit the improper motor response, is often assessed by a Stop Signal Task (SST) (Bartholdy, Dalton, O'Daly, Campbell, & Schmidt, 2016; Verbruggen et al., 2008) and Go/ No Go Task (Verbruggen & Logan, 2008). The previous study has reported that as long as the trails proceed in the Go/ No-Go Task, the inhibition of the improper motor response became automatic and top-down inhibition is less involved (Verbruggen & Logan, 2008). This learning effect may potentially bias the subjects' performance on the inhibition responses in the Go/ No-Go Task (Verbruggen & Logan, 2008). However, the inconsistent trails setting in the Stop Signal Task (SST) can prevent the inhibition of the improper motor response to become automatic, and top-down inhibition is involved as long as the trails proceed (Verbruggen & Logan, 2008). Therefore, the Stop Signal Task (SST) is chosen over the Go/ No-Go Task as one of the measures used for inhibitory control.

In the context of eating behaviour, it has been demonstrated that inhibitory self-control can be related to snacking behaviour (Levitan et al., 2015; Nederkoorn, 2014). Also, this behavioural trait has been revealed in associating with restrained eating (Wu et al., 2013) and emotional eating (Svaldi, Naumann, Trentowska, & Schmitz, 2014). However, a recent review pointed out that stop signal tasks (SST) had little effect on food intake in healthy adults (Bartholdy et al., 2016). Therefore, there is a need to further validate the use of SST for assessing eating behaviours.

1.6.4 General trait versus domain-specific self-control in food-related behaviour

Research on self-control encompasses a wide range of disciplines and is therefore conceptualised in many ways (De Ridder et al., 2012; Duckworth & Kern, 2011). A number of different self-control measures, including general self-control and domain-specific self-control, were developed to understand the individual difference in self-control (Duckworth & Kern, 2011; Haws et al., 2016b). The most frequently employed method in prior literature is the explicit measure of general trait self-control, established by Tangney et al. (2004), developed based on the comprehensive review from previous studies measuring self-control. This measure had been quoted in the excess of 4,900 times. Latest research suggested that food self-control (FSC) could facilitate greater insights into various eating scenarios (food domain), which was recently developed from trait self-control measure (Haws, Davis, & Dholakia, 2016b). Emerging data have suggested that FSC, regarded as a validated self-reported measure, could be particularly useful for capturing individual differences in different eating behaviour (Haws, Davis, & Dholakia, 2016a). Haws and her colleagues carried out 8 empirical studies to examine the relationship between self-control (general trait self-control: *i.e.* Tangney's Brief Self-Control Scale; domain-specific self-control: *i.e.* Food Self-Control Scale) and eating behaviour (*i.e.* food choice and real food consumption) (Haws et al., 2016a; Haws et al., 2016b). Findings from these two research suggested that food self-control measure is recommended to be used to determine individuals' eating behaviour in different eating scenarios (Haws et al., 2016a; Haws et al., 2016b). Although food self-control could facilitate greater insights into various eating scenarios (Haws et al., 2016a; Haws et al., 2016b), only one study examined the predictive ability of food self-control scale (n = 180, 99 females) on real food consumption (*i.e.* cheese crackers), the result has found little effect of food self-control on snack intake (p = 0.055) (Haws, Davis, & Dholakia, 2016b). Food self-control (FSC) is yet to be examined, particularly in the context of portion size and energy density. Therefore, further investigation is needed to apply food self-control (FSC) in assessing PS and ED in order to further validate the effectiveness of FSC measures.

1.7 Several important factors affecting food choice and food intake

Several factors include internal (hunger, disinhibited eating) and external factor (hedonic responses) can affect food choice and food intake.

1.7.1 Hunger

Initially, physiologists believed that hunger was caused by the stomach due to a lack of food or empty in the stomach (Carlson, 1913). Another study showed that after the nerves of the stomach of the animal were removed, hunger still existed, and the animals still showed obvious feeding behaviour (Cannon & Washburn, 1912). Subsequent studies have shown that the hunger sensation is related to the absolute level of blood sugar, and when blood sugar drops, the nerve centre is stimulated to produce a feeling of hunger (Cannon & Washburn, 1993). With the development of modern medicine, scholars have found that the human hypothalamic feeding centre and the nerve cells in the satiety centre control human hunger, which is very sensitive to changes in blood glucose concentration or lipid concentration (Rodin, 1985). When the blood glucose level is lowered, the nerve cells in the feeding centre are stimulated, causing hunger (Anand, 1961). When people are hungry, the body's energy metabolism and various physiological systems will produce a series of changes, such as changes in the secretion of substances and the reduction of the function of the central nervous system from the brain (Ahima & Antwi, 2008).

Previous studies have suggested that fasting increased food reward activity in brain areas when exposed to high-calorie foods (Siep et al., 2009). Expectedly, emerging data confirmed the association between energy depletion and reduced self-control, suggesting that a fasting state promotes increased impulsive behaviour (DeWall, Deckman, Gailliot, & Bushman, 2011). Baumeister, Vohs, et al. (2007) proposed the strength model of self-control, which shows that self-control operates on the basis of a limited resource. An accumulating amount of evidence on the strength model of self-control has been investigated in eating behaviour scenarios (Hagger, Wood, Stiff, & Chatzisarantis, 2009). The evidence on the strength model of self-control suggests that self-control is similar to energy or strength, in that it can become depleted through use (Baumeister, Vohs, et al., 2007). However, other studies showed no relationship between energy intake and hunger level (Fay, White, Finlayson, & King, 2015). Moreover, a previous food deprivation study on eating disorders, which found that there was no increase in food consumption for those people without eating disorders (control group), after 19 hours fasting (Hetherington, Stoner, Andersen, & Rolls, 2000). The latest research on food deprivation suggested that 24 hours of fasting failed to cause an increase in food intake for the next four days *ad libitum* sessions (Levitsky & DeRosimo, 2010). This evidence is inconsistent with literature, which has found that skipping meals did not cause adequate compensation for the decrease in food intake (Levitsky, 2005). Therefore, this inconsistency has motivated further exploration on how fasting moderates self-control on eating behaviours.

1.7.2 Hedonic response

Hedonic experience elicited by food is a primary driver of eating (Blundell, Dalton, & Finlayson, 2013; Horner, Finlayson, Byrne, & King, 2016). Indeed, enhanced liking for a specific food leads to increased susceptibility to overeating (Finlayson & Dalton, 2012). Recent studies have suggested that hedonic responses to food can be reflected by implicit wanting and explicit liking (Dalton & Finlayson, 2014). Explicit liking refers to the pleasure perception or expectation obtained from food, the evaluation of sensory characteristics or a judgement of the level of pleasure it provokes in an explicit (subjective, conscious) way. However, implicit wanting is understood as the appeal or desire that is activated by perceiving of food or a food-associated cues in the context in an implicit (automatic, unconscious) way (Finlayson, Arlotti, Dalton, King, & Blundell, 2011). Further studies demonstrated differentiation between these two constructs by research in appetite control (Finlayson, King, & Blundell, 2008), binge eating (Dalton & Finlayson, 2014) and anorexia nervosa (Cowdrey, Finlayson, & Park, 2013). Findings from these studies indicate that implicit wanting and explicit liking are complementary measures of hedonic responses to food.

1.7.3 Disinhibited eating

Disinhibited eating reflects the tendency of a habitual overeating and opportunistic eating in a food-rich environment (Bryant, King, & Blundell, 2008; Preedy, Watson, & Martin, 2011), which is typically characterised by emotional eating and external eating that are easily induced in a food-cues-rich environment (Bryant et al., 2008). The disinhibited eating targets on a trait of eating behaviour. According to Baumeister (2002), self-control refers to the capability to inhibit impulses in order to achieve long-term goals. The self-control is a general trait, it can be self-control in any domains such as eating or spending money. Early studies used a disinhibition subscale in the Three

Factor Eating Questionnaire (TFEQ) to examine disinhibited eating among restrained eaters (Stunkard & Messick, 1985). Previous study found that individuals who scored higher on disinhibited eating levels reported more high-risk eating behaviours, such as overeating or vomiting for food control (Westenhoefer, 1991). Later studies have used the mean score of emotional eating (DEBQ-Em) and external eating (DEBQ-Ex) subscales from the Dutch Eating Behaviour Questionnaire (DEBQ) as individuals' disinhibiting eating tendency with the advantage of greater reliability and reliability (Van Strien, Frijters, Bergers, & Defares, 1986a). DEBQ also consists of Restrained eating (DEBQ-R). Fay and Finlayson (2011) suggested that combine all subscales in DEBQ (high disinhibited restrained eaters) are more sensitive to reflect an individual difference in eating behaviour than each subscale alone (restrained eaters). High disinhibited restrained eater refers to the person has an intentional restriction of caloric intake for the purpose of weight loss or weight maintenance, but fails to sustain the restriction of caloric intake due to high tendency of a habitual overeating (Fay & Finlayson, 2011).

A previous study carried out by Weng, Chen and Zhu (2012) examined the attentional biases of high disinhibited restrained eaters and low disinhibited restrained eaters on delicious food pictures. This study found that high disinhibited restrained eaters had difficulty in distracting attention from high energy savoury foods, while low disinhibited restrained eaters showed attentional avoidance to delicious food cues. Therefore, low disinhibited restrained eaters may have high self-control, top-down processes involved in a conscious way that direct attention to the goal-related food cues (Kean & Lambert, 2003). Tempting high energy density food (HEDF) automatically triggering a bottom-up process for these low self-control individuals, which drives high disinhibited restrained eaters' attention to approach them (van Koningsbruggen et al., 2017). Another study investigated the effects of emotions on the eating behaviour for high disinhibited restrained eaters and low disinhibited restrained under emotionally induced conditions. Findings from this study indicate that individuals with high disinhibited restrained eaters had an increased food intake. It suggested that there was more “unsuccessful” control in restrained eating under mood-inducing operations, which may further develop into weight gain or eating disorders (Fay & Finlayson, 2011). In addition, other evidence suggests that individuals with high disinhibited restrained eaters have more difficulties to resist the temptation of delicious foods (Houben, Roefs, & Jansen, 2012), which implies high disinhibited restrained eaters have low self-control (Stroebe, Van Koningsbruggen, Papies, & Aarts, 2013; Tseng & Hu, 2012). It may be one of the reasons why they are more likely to develop problematic dietary behaviours.

Previous studies have suggested that individuals with high disinhibited eating were more likely to have a higher intake of chocolate cookies and savoury crackers consumption (Ouwens, van Strien, & van der Staak, 2003a, 2003b). However, some studies found that there was no association between disinhibited eating and ice cream and milkshake intake (Ouwens, van Strien, & van der Staak, 2007; Van Strien, Cleven, & Schippers, 2000). For the top-down process, self-control has also been suggested as a critical factor for regulating eating behaviour (Metcalfe & Mischel, 1999). High and low self-control individuals differ in their motives and propensity to exhibit different levels of self-control in eating behaviour (Hofmann, Baumeister, et al., 2012). Previous studies found the moderating role of self-control on the variety effects of food consumption, high self-control individuals had less desire for food and decreased food intake in the presence of multi-foods (Haws & Redden, 2013). Another study found that the moderating role of self-control on the relationship between purchase tendency and snack consumption, low self-control individuals are more susceptible to the relationship between purchase tendency and snack consumption (Honkanen et al., 2012). Inconsistencies about the relationship between disinhibited eating and food intake could be related to the lack of considering top-down control processes. Hence more research is clearly needed to unravel how self-control moderates disinhibited eating in the food choice and food consumption context.

1.8 Cognitive training on eating behaviour changes

Body image refers to the integration of an individual's perception, emotions and thoughts of their body (Grogan, 2006). The information processing of body image involves body dissatisfaction, which refers to the gap between the individual's perception of their current body and the ideal body (Bulik et al., 2001). This gap can result in a negative evaluation of their body’s appearance; experiencing negative affect and corresponding behavioural regulation towards body weight (Cash & Deagle III, 1997; Cash & Pruzinsky, 2004). Body dissatisfaction has become a global problem, and "normative discontent" has become a widely used term to describe the high incidences of body dissatisfaction (Tiggemann, 2011). Emerging evidence suggests that the proportion of those willing to change body shape reached 60% for girls and 30% for boys (Ricciardelli & McCabe, 2001). Furthermore, numerous studies have revealed that problems with body dissatisfaction, eating disorders and excessive weight have shown a linear growth in an eastern society such as in China and Hong Kong (Chen & Jackson, 2009; Lee, Leung, Lee, Yu, & Leung, 1996; Li, Hu, Ma, Wu, & Ma, 2005). For instance, more than 50% of Chinese children and adolescents from the normal weight group are dissatisfied with their bodies and the dissatisfaction is even higher in overweight and lean groups (Li et al., 2005).

Recently, extensive research has been conducted to identify the intervention methods that help individuals with changing behaviour (Blume, Ford, Baldwin, & Huang, 2010; Hardeman et al., 2002; Webb, Joseph, Yardley, & Michie, 2010). One of the validated measures is cognitive training to modify implicit evaluations based on the dual-system model (Stice, Lawrence, Kemps, & Veling, 2016; Strack & Deutsch, 2004; van Beurden, Greaves, Smith, & Abraham, 2016). Psychological studies have suggested that Evaluative Conditioning (EC) and the Implicit Association Test (IAT), two similar processes, can be employed for modifying implicit evaluations (De Houwer, Thomas, & Baeyens, 2001; Ebert, Steffens, Von Stülpnagel, & Jelenec, 2009). Both trainings involved in food stimuli and body figures (See section 1.8.1 and 1.8.2).

Previous research which assessed the effectiveness of modifying implicit evaluation, via EC or IAT, on behaviour change has produced a mixture of findings. While some studies support the successful modification of implicit evaluation in altering subsequent alcohol drinking behaviour (Houben, Havermans, & Wiers, 2010; Houben, Schoenmakers, & Wiers, 2010), healthy food choices (Hollands, Prestwich, & Marteau, 2011; Walsh & Kiviniemi, 2014) or decreased unhealthy snack intake (Haynes, Kemps, & Moffitt, 2015), other studies have shown no effects of modifying implicit evaluation on behaviour (Ebert et al., 2009; Lebens et al., 2011). Inconsistencies in the literature have motivated further exploration for the effectiveness of modifying implicit evaluation on behaviour changes.

1.8.1 Evaluative conditioning (EC)

EC is based on changing the association structure, which includes the learning process of the new evaluation (Gawronski & Bodenhausen, 2011). With the classic EC, participants are asked to assess their affective reactions in different evoked conditions that involve pairing conditioned stimulus (CS; ***e.g.*** high calories food) with the unconditioned stimulus (UCS; ***e.g.*** lean or fat figure pictures) (De Houwer et al., 2001). For instance, previous EC studies on pairing unhealthy snacks with adverse pictures (***e.g.*** fat figure pictures) suggest that participants assessed unhealthy food more negatively in EC than control conditions (Hollands et al., 2011; Lebens et al., 2011).

1.8.2 Implicit association test training

A conventional IAT is used to assess an individual’s implicit associations (Greenwald et al., 1998). However, IAT training paradigm is consistently pairing certain concepts, the aim is to build new associations (Gawronski & Bodenhausen, 2011). The IAT training is based on the activation of different associations stored in the memory (Gawronski & Bodenhausen, 2011). During the task, participants are asked to respond to the displayed word or pictures as fast as possible by pressing the left or right key corresponding to the correct prescribed paired target-attribute category (positive CS-

UCS; ***e.g.*** low-calorie food with lean figures or negative CS-UCS; ***e.g.*** high-calorie food with fat figures) (Greenwald et al., 1998). For example, a previous study suggested that modified IAT as an alternative of evaluative conditioning can effectively modify participants' implicit attitudes towards candy brands, with assessing negative CS-UCS pairs more negatively than another brand (Ebert et al., 2009).

1.9 Aim and objectives

Much research has been done to better understand the effect of self-control on individual eating behaviour. This previous research affirms self-control is crucial for keeping a homeostatic balance in an obesogenic environment. However, the measurement of self-control show diversity due to different self-control theories was proposed. The comparison between the self-control measures is theoretically important. Therefore, there is a need to pinpoint the most effective approach to assess self-control in the context of food choices.

Emerging data suggest that two distinguishable processes determine food intake, which are bottom-up food reward drives and top-down impulse controls processes. Particularly for the bottom-up process, liking elicited by food is a primary driver of eating (Blundell et al., 2013). For the top-down process, self-control has also been suggested to be a critical factor for regulating eating behaviour (Metcalfe & Mischel, 1999). Prior studies that have assessed the relationship between disinhibited eating on food consumption have observed conflicting findings. The inconsistencies about the relationship between disinhibited eating and food intake could be related to the lack of considering bottom-up and top-down processes. Hence more research is clearly needed to unravel the role of liking and self-control in this relationship in food choice and food consumption.

Empirical studies have found self-control plays a crucial role in regulating energy intake (De Ridder et al., 2012). In fact, total energy intake is determined by portion size

(PS) and energy density (ED) of food. However, there is little understanding of the effect of self-control on PS and ED. The previous study has confirmed the association between energy depletion and reduced self-control, suggested fasting state promotes increased impulsive behaviour (DeWall et al., 2011). It remains unknown how fasting moderates self-control on portion size and energy density of the food.

Cognitive training has been demonstrated successful for behaviour interventions (Baer, 2003; Blume et al., 2010). Implicit association test as one of the widely cited cognitive training methods has been demonstrated successful for behaviour interventions (Greenwald et al., 1998; Haynes et al., 2015). Although the implicit evaluation training on subsequent behaviour has been investigated in different disciplines (Devine, Forscher, Austin, & Cox, 2012; Girod et al., 2016), its effectiveness in portion size and energy density of food have not been investigated.

1.9.1 Overall aim of thesis research

The current thesis research was to systematically test for the role of self-control in determining an individual's eating behaviour. Specifically, the thesis discussed the role of self-control in influencing an individual's food choice, energy intake, portion size and energy density in different eating scenarios. In addition, the thesis investigated the possibility of a cognitive training paradigm in decreasing food consumption.

1.9.2 Specific objectives of thesis research

This thesis is aimed to

1. Assess the effectiveness of different self-control measures for predicting an individual's food choices (Chapter 2).

2. Explore the role of self-control in the disinhibited eating on food choice (Chapter 2) and food consumption (Chapter 3).

3. Examine the direct and moderating role of self-control on energy intake across diverse food categories in different eating scenarios (Chapter 3).

4. Test the effect of food self-control on the two primary determinants of energy intake – portion size and energy density in fasting and non-fasting scenario (Chapter 4).

5. Test a cognitive training paradigm on intervening portion size and energy density for low self-control individuals (Chapter 5)

The first objective was achieved by comparing the effectiveness of three common experimental measures of self-control for predicting food behavioural forced-choice responses (Chapter 2). This provided suggestions for effective assessments of self-control in the food context. Further analysis was carried out for the moderating role of self-control on the relationship between disinhibited eating and food choice (Chapter 2). Following this study, the direction of research focused on food consumption in different eating scenarios.

In order to achieve the second and third objectives, the role of self-control was tested in sweet food, savoury snack and main meal eating scenarios (Chapter 3). Both top-down impulse control and bottom-up food reward processes on energy intake were identified across different food types.

The fourth and fifth objectives provided an understanding of the role of food self-control in regulating portion size and energy density of food (Chapter 4). Both food choice and food consumption contexts were applied in fasting and non-fasting condition. This contributed to possible paths of an intervention strategy for those low self-control individuals.

A cognitive training paradigm was developed and initially used to test its effectiveness on decreasing portion size and energy density of individuals with low self-control (Chapter 5). This was achieved by using a mixed design in the context of real buffet eating scenarios.

Chapter 6 further discussed the finding of current doctoral research, further explained the role of self-control and its mechanism in regulating eating behaviour. Suggestions were made for effective measuring self-control and eating behaviour. A number of limitations were mentioned, and future studies built on the current research findings were recommended.

A schematic illustration of the studies carried out to attain the objectives of this thesis research can be seen in section 1.9.3.

1.9.3 Schematic illustrating thesis research

Overall aim: Assessment of the role of self-control in determining individuals' eating behaviour in different eating scenarios.

Chapter 2: ***The role of self-control in determining food behavioural forced-choice responses***

Objective: To assess the moderating role of high and low self-control individuals in food behavioural forced-choice responses and examined the effectiveness of self-control measures for predicting food choice.

Findings: The moderating role of self-control was only found among high self-control individuals in the context of food choice. Explicit self-control was the most effective method for predicting food choice, which was selected for proceeding research.

Chapter 3: ***Assessing the role of self-control in different eating scenarios***

Objectives: To assess the direct and moderating role of self-control in energy intake across different food categories.

Findings: Explicit self-control had no direct effect on energy intake across diverse food categories. The moderating role of self-control was found in sweet and savoury snack energy intake, but not main meal one.

Chapter 4: ***The effect of self-control on portion size and energy density of food***

Objectives: To test the direct effect of self-control on portion size and energy density.

Findings: Self-control only had a direct effect on energy density, but not on portion size. The finding indicated the possible direction of intervention strategy via energy density in the proceeding study.

Chapter 5: ***The effectiveness of cognitive training on decreasing portion size and energy density of food***

Objectives: To examine the effectiveness of cognitive training for an acute effect on decreasing portion size and energy density of the food.

Findings: Modified IAT had no acute effect on reducing portion size and energy density of food for an individual with low food self-control.

Chapter 2: The role of self-control in determining food behavioural forced-choice responses

In preparation for submission to Appetite

Geng, X., Mirosa, M., Oey, I. & Peng, M. The role of self-control in determining food behavioural forced-choice responses. *Appetite (in preparation)*.

2.1 Summary

Previous research on eating behaviour has recognised the important role of self-control in maintaining a homeostatic balance in the modern obesogenic environment. However, assessment methods for an individual's self-control in the context of food choice are not yet evaluated. The purpose of the chapter was to examine the effectiveness of common experimental measures of self-control for predicting behavioural forced-choice responses (BFCR) for high-calorie and low-calorie food (HCF and LCF). Specifically, three methods – inhibitory control test, implicit and explicit self-control task – were employed to profile the self-control trait of 116 female participants. These three measures were then analysed against the participant's BFCR to various food products and self-reported eating behaviour. Results derived from hierarchical regression and Pearson's correlation revealed that the explicit self-control (*i.e.* a Tangney's Brief Self-Control Scale) was the most effective approach for predicting BFCR to palatable food. In addition, there was no significant correlation between these tested self-control measures, suggesting they were analogous to different self-control processes. The moderation analysis suggested explicit self-control moderated the relationship between disinhibited eating and BFCR such that a positive relationship was observed in individuals with high self-control. Overall, this chapter systematically tested the role of self-control in the context of food choice and provided suggestions for effective assessments. Future research should replicate the current findings with other food types and in different eating scenarios.

2.2 Introduction

Much research has been done to better understand the effect of self-control on individual eating behaviour (De Ridder et al., 2012; Herman & Mack, 1975; Wardle, 1987). This previous research affirms self-control is crucial for keeping a homeostatic balance in the obesogenic environment (Johnson et al., 2012). However, self-control has been conceptualised in different ways (Duckworth & Kern, 2011). Psychology studies have suggested that self-control emerges as two distinguishable processes, involving the reflective (***i.e.*** explicit) and impulsive (***i.e.*** implicit) systems (Hofmann et al., 2009; Keatley et al., 2017; Strack & Deutsch, 2004). Therefore, self-control is recommended to be assessed with both explicit and implicit methods (De Ridder et al., 2012; Duckworth & Kern, 2011). In addition, inhibitory control as a behavioural trait has also been suggested to be a critical factor for regulating behaviour (Barkley, 1997). Studies have demonstrated that the construct of self-control between explicit measures and behavioural measures did not overlap, which reflected distinct processes in self-control (Allom, Panetta, Mullan, & Hagger, 2016). However, a previous study carried out by Allom et al. (2016) did not take the implicit self-control into account. Therefore, there is a need to observe the relationship between inhibitory, implicit and explicit self-control measures in order to examine whether they assess the same construct.

In the context of eating behaviour, previous studies on explicit self-control measures suggested that positive impacts of effective self-control have been demonstrated in fruit and vegetable consumption (Wills et al., 2007) and high-fat food intake (Gerrits et al., 2010). Also, studies have revealed that inhibitory self-control plays an important role in eating behaviours that include sugar and carbohydrate consumption (Levitan et al., 2015), food intake (Guerrieri et al., 2007) and calories of snack purchasing (Nederkoorn, 2014). However, no study has considered an implicit self-control method in the field of eating behaviour. The measurement of self-control show diversity due to different self-control theories was proposed. The comparison between the self-control measures is theoretically important, particularly in the context of food choice. Therefore, more research is needed to pinpoint the most effective approach to assess self-control in the context of food choices.

Previous studies have suggested that individuals with high disinhibited eating were more likely to have a higher intake of chocolate cookies and savoury crackers consumption (Ouwens et al., 2003a, 2003b). However, some studies found that there was no association between disinhibited eating and ice cream and milkshake intake (Ouwens et al., 2007; Van Strien et al., 2000). Inconsistencies relating to disinhibited eating and food consumption in the literature remain unknown. Emerging data have suggested top-down impulse controls process determines food intake (Gerlach, Herpertz, & Loeber, 2015; van der Laan & Smeets, 2015). For the top-down process, self-control has also been suggested as a critical factor for regulating eating behaviour (Metcalfe & Mischel, 1999). High and low self-control individuals differ in their motives and propensity to exhibit different levels of self-control in eating behaviour (Hofmann, Baumeister, et al., 2012). Previous studies found the moderating role of self-control on the variety effects of food consumption, high self-control individuals had less desire for food and decreased food intake in the presence of multi-foods (Haws & Redden, 2013). Another study found that the moderating role of self-control on the relationship between purchase tendency and snack consumption, low self-control individuals are more susceptible to the relationship between purchase tendency and snack consumption (Honkanen et al., 2012). Inconsistencies about the relationship between disinhibited eating and food intake could be related to the lack of considering top-down control processes. Hence more research is clearly needed to unravel how self-control moderates disinhibited eating in the food choice context.

The aim of the present chapter was three-fold. First, data from this study examined concordance across self-control measures derived from three common methods. Second, this study assessed the effectiveness of different self-control measures for predicting behavioural forced-choice responses to high- and low-calorie food (LCF). Third, this study examined whether self-control moderated disinhibited eating in the context of food choices. Findings from this chapter provided important insights into the role of self-control in food choice and offered suggestions for its assessment approach.

2.3 Methods

2.3.1 Participants

Participants were recruited using flyers advertised on notice boards of students' association, different academic departments of the University of Otago, and Facebook groups of the Dunedin community. In total, 120 females were recruited based on a prior screening procedure to exclude those participants who were currently taking medication and whose English was not their first language. Four participants were removed due to the missing data. Therefore, the sample size of this study was 116 females (N = 116; M_{age} = 23.06, SD = 5.78, Range:18-44) that were selected to do further data analysis. In consistent with previous research, the current study focused on females participants only, as food craving was shown to be more prevalent in females than males (Weingarten & Elston, 1991). Participants were tested between 9:00 and 17:00h in a standard sensory facility at the Department of Food Science. All participants were asked to abstain from any food or non-water beverage consumption for at least two hours prior to the experiment. An informed written consent was completed before the experiment. All participants received a NZ$10 supermarket voucher compensation after the experiment debriefing[1].

2.3.2 Food stimuli

The visual stimuli used in the current study consisted of 10 food images (Figure 2.1), which was consistent with previous research (Teslovich et al., 2014). They were photographed from real foods, which were downloaded from the test library of the

[1] Ethical approval for this study was granted by the Human Ethics Committee of the University of Otago (Reference number: 17/085).

millisecond main website (https://www.millisecond.com/download/library/). All food cues were categorised into two groups of foods based on their calorie content. The high-calorie food group consisted of 5 types of sweets (*i.e.*, Cookies, Cake, Donuts, Ice cream and Chocolate), whereas the low-calorie food group consisted of 5 types of fruits (*i.e.*, Apple, Banana, Kiwi fruit, Peach and Strawberry). The food images have been homogeneously set up into the same size (weight 800 pixels; height 530 pixels; 300 dpi resolution) with a black background. All food images have been tested with high internal consistency (Cronbach's *a* from 0.90 to 0.99) in previous research on its valence and arousal using 7-points Likert scale in previous research (Teslovich et al., 2014).

Low-Calorie Food (LCF) **High-Calorie Food (HCF)**

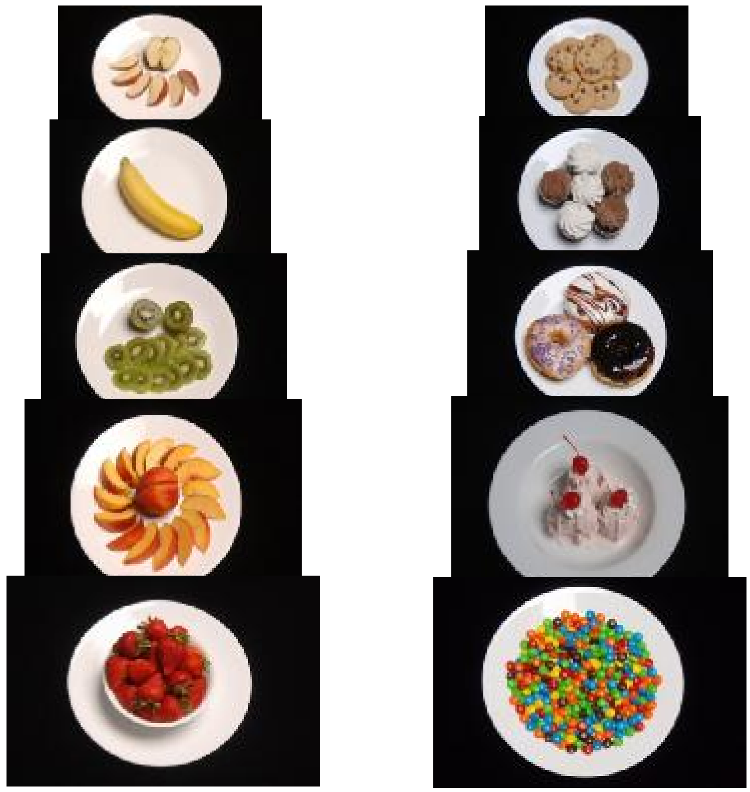

Figure 2.1 - Low-Calorie Food (LCF) and High-Calorie Food (HCF) used in the current study; food images obtained from the previous study (Teslovich et al., 2014).

2.3.3 Procedure

The 50-minute test consisted of one hunger level check task, three self-control tasks, one food choice task and one eating behaviour questionnaire (Figure 2.2). Participants were asked to conduct self-control tasks for measuring an individual's self-control ability, then to perform a food choice task, followed by an explicit self-control task, then participants were asked to fill out The Dutch Eating Behaviour Questionnaire (DEBQ). Upon the completion of the test, information about the participants' height and weight was collected to calculate Body Mass Index (BMI; kg/m^2). A 3-minutes break was arranged after finishing each task as a precaution against participants' fatigue.

The experiment was conducted using the iPad Air 2® (Apple, USA) table computer on IOS 10 system with 9.7-inch monitor. Data for the implicit response task was collected with installed psychology software INQUISIT online version (Millisecond Software LLC, Seattle, WA, V5.0.14.0), and all other response data were collected using Qualtrics© (USA, 2016). To be consistent with previous research, all explicit measures were organised after data collection of implicit measures (Bosson, Swann, & Pennebaker, 2000; Wiers, Van Woerden, Smulders, & De Jong, 2002). The reason to collect the explicit measures after the implicit measures is that the carryover effects of implicit measures to explicit measures appear to be smaller than vice versa (Bosson et al., 2000; Wiers et al., 2002).

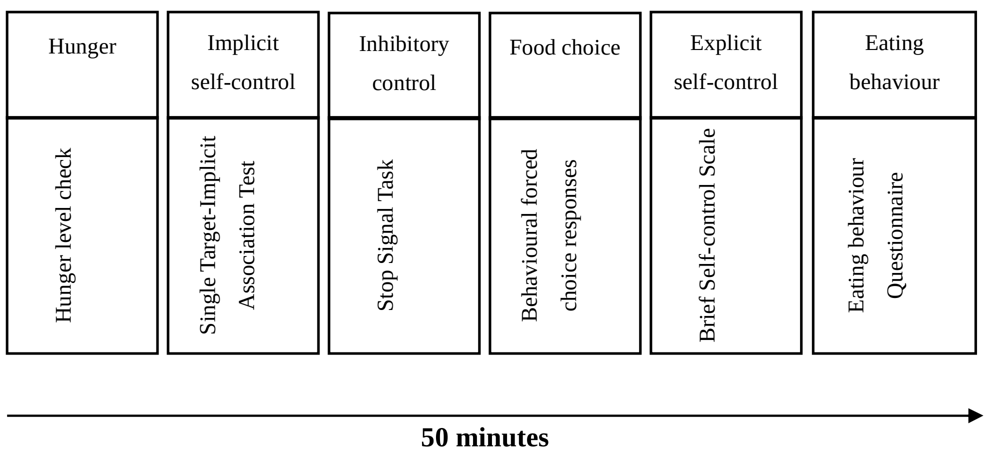

Figure 2.2 - An outline of the experimental events (according to time and order) and the various tasks for each experiment.

Hunger level

Participants were instructed to rate a question on hunger level “how hungry are you feeling at this moment?” by using a 100-mm *Visual Analogue Scale* (*VAS*) anchored from “Not at all” (0) to “Extremely” (100) (Flint, Raben, Blundell, & Astrup, 2000).

Single-Target Implicit Association Test

Implicit self-control (ISC) was measured by a single target-implicit association test (ST-IAT). Words stimuli of two attributes and one target included ‘self-control’ (controlled, cautious, planned, disciplined, orderly, considered), ‘impulsivity’ (impulsive, free, careless, spontaneous, hasty, chaotic) and ‘self’ (I, me, my, mine, self), which were selected from implicit measures of self-control and impulsivity (Huntjens, Rijkeboer, Krakau, & De Jong, 2014; Keatley et al., 2017). The whole ST-IAT task contained 5 blocks (Figure 2.3), blocks A1, A2 and A4 were practice blocks that comprised 20 trials in each one. Blocks A3 and A5 were test blocks that consisted of 40 test trials. In the test block, participants were assigned to one of two combined pairs (***e.g.***, left computer key for ‘self’-‘self-control’ and right key for ‘impulsivity’), then the pairs were switched in a second combined task (***e.g.***, left computer key for ‘self-control’ and right key for ‘self’-‘impulsivity’). The pairs were displayed in the left-hand and right-hand corners of the screen. Participants were asked to respond by pressing the left key or right key on the keyboard to select relevant stimuli. The order of the test blocks within the ST-IAT was counterbalanced. The D-score algorithm (standardized mean reaction time difference between identifying ‘self’ to ‘self-control’ and identifying ‘self’ to ‘impulsivity’) was used to calculate the ST-IATs score with lower scores denoting lower levels of implicit self-control (Greenwald et al., 1998).

$$\text{D-score} = (t_{\text{self-control}} - t_{\text{impulsivity}})/\sigma_{\text{pooled}}$$

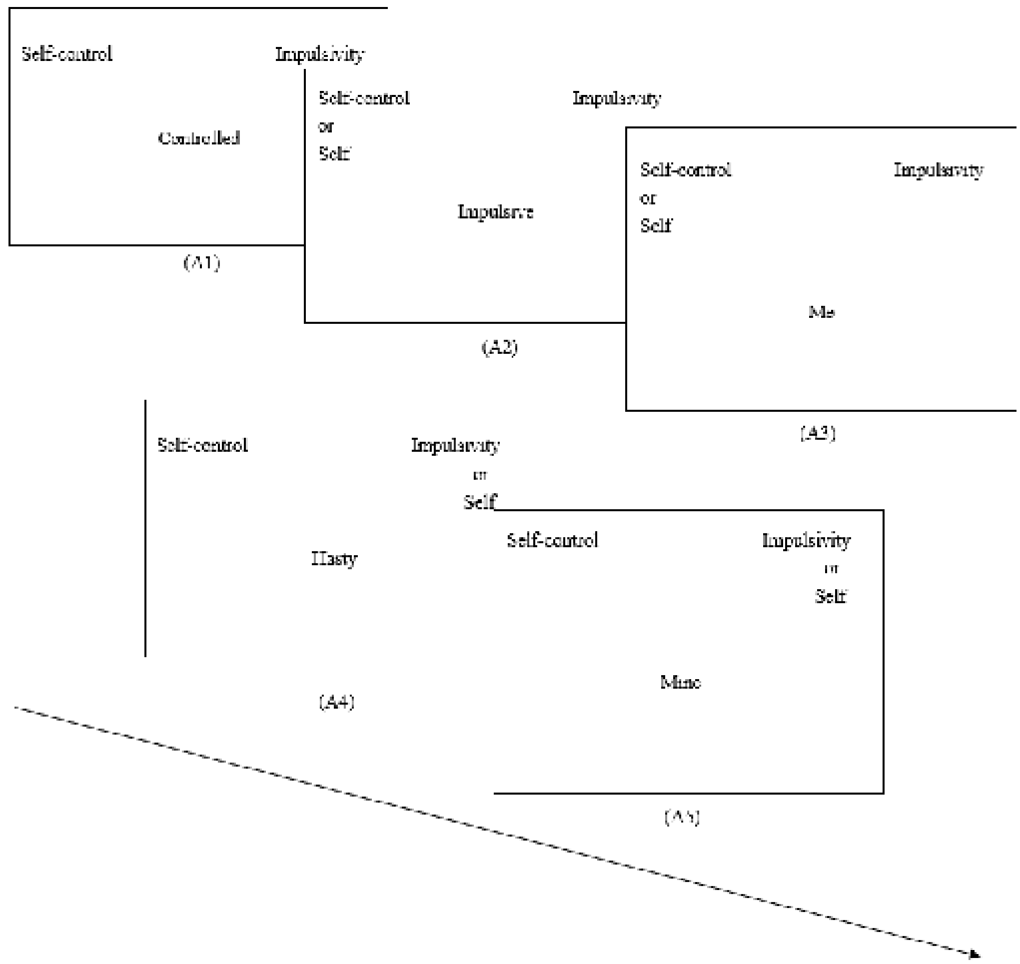

Figure 2.3 - The five squares represent five blocks (A1-A5) of a single target-implicit association test of implicit self-control measure.

Stop Signal Task

Inhibitory control was assessed by a stop-signal task (SST) that involved a ‘go’ and ‘stop’ task (Verbruggen et al., 2008). A fixation circle was shown first in the middle of the screen, then participants were shown an arrow that either directs right or left in this circle. For the ‘go’ task, participants were instructed to press the left corresponding key “E” if the arrow pointed left and to press the right corresponding key “I” if the arrow pointed right. For the ‘stop’ task (25%), participants were asked to inhibit this response after a beeping sound. The first stop signal was blocked to 250ms after the presentation of the arrow with 50ms adjustment based on the participants’ performance. If participants successfully inhibit the response, the stop signal increased by 50ms. If the contrary were true, stop signals decreased by 50ms. The stop signal appeared between a minimum of 50ms and a maximum of 1150ms. SST comprised the 1 practice block (32 trials) and 3 test blocks (64 trials each). The ratio of occurrence frequency between signal trials and no signal trials in these four blocks was 1:3. Stop signal reaction time (SSRT) was calculated by subtracting the mean stop-signal delay from the mean no-signal reaction time (Logan et al., 1997). A longer stop-signal reaction time indicates an inferior response inhibition. Studies have demonstrated good reliability of this behavioural task (Congdon et al., 2012).

Brief Self-Control Scale

Explicit self-control was measured by Tangney's Brief Self-Control Scale (BSCS) (Maloney et al., 2012; Tangney et al., 2004). Participants were asked to rate their level of agreement to each of 13 statements on a 5-point Likert scale (***e.g.***, I refuse things that are bad for me; 1 = not at all like me; 5 = very much like me) (Appendix 1). The average score across all items represents the individual's self-control measure, with lower scores indicating poorer self-control. The internal consistency coefficient alpha for BSCS scale was high in the current study, Cronbach's ***a*** = 0.84.

Food choice task

The choice of food items was measured using the behavioural forced-choice response (BFCR) method (Dalton & Finlayson, 2014). In this task, participants were instructed to place their index fingers on the "E" and "I" key of the iPad keyboard. When a fixation cross was shown in the middle of the screen, participants were presented with several paired foods randomly chosen from each category (Figure 2.4) and were instructed to select the food they "most want to eat now" as accurately and quickly as possible. If the desired item appeared on the left, participants pressed the "E" key; if the item appeared on the right, participants pressed the "I" key. The inter-trial interval was randomly selected from the following five-time intervals (500ms, 800ms, 1200ms, 1600ms or 2000ms). The whole task composed of one practice block (24 trials) and one test block (50 trials). The reaction times (RTs) from all trials were recorded for calculating behavioural forced-choice scores, using the frequency-weighed algorithm. This algorithm considers the reaction time and how frequent food stimuli from both categories is selected and is not selected. The behavioural forced-choice responses (BFCR) score is calculated by the following steps: (1) compute the mean of all reaction times; (2) calculate the time ratio of each selected food item in the selected category by using mean of all reaction times divided by the reaction time of each selected food item in the selected category (*e.g.* Low-Calorie Food: fruits), then sum up time ratio of all selected food items; (3) calculate time ratio of each non-selected food item in the non-selected category by using mean of all reaction times divided by the reaction time of each non-selected food item in the non-selected category (*e.g.* High-Calorie Food: sweets), then sum up time ratio of all non-selected food items; (4) calculate the difference between time ratio of all selected food items and all non-selected food items. With this BFCR score, a positive value denotes a stronger preference for a given food category, relative to the alternatives. A zero on this score means both categories are equally preferred (French, Mitchell, Finlayson, Blundell, & Jeffery, 2014).

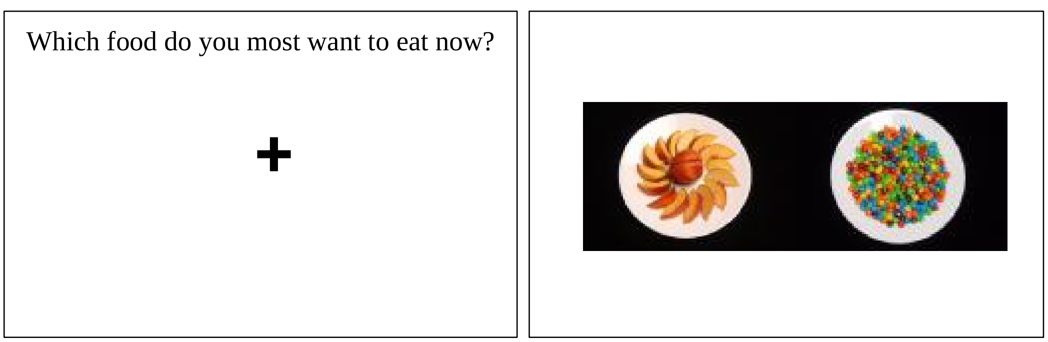

Figure 2.4 - Representation of trials in behavioural forced-choice responses towards high- and low-calorie food.

Eating behaviour questionnaire

Restrained eating (DEBQ-R), Emotional eating (DEBQ-Em) and External eating (DEBQ-Ex) subscales of the Dutch Eating Behaviour Questionnaire (DEBQ) were used to assess eating behaviour tendencies (Appendix 3) (Van Strien, Frijters, Bergers, & Defares, 1986b). Participants were instructed to rate 10-item Restrained eating (DEBQ-R) (***e.g.*** "Do you deliberately eat less in order not to become heavier?"), 13-item emotional eating (DEBQ-Em) (***e.g.*** "Do you have a desire to eat when things are going against you or when things have gone wrong?") and 10-item external eating (DEBQ-Ex) (***e.g.***, "If you see or smell something delicious, do you have a desire to eat it?") on a 5-point Likert scale, ranging from 1 (never) to 5 (very often).

The scores of all items in each subscale were calculated. Higher average scores indicate higher levels of restrained eating behaviour tendencies. The average score of DEBQ-Em and DEBQ-Ex subscale was calculated for obtaining disinhibited eating measure, with a higher average score indicating more disinhibited eating tendencies (Ouwens et al., 2003b). The internal consistency coefficient alpha for restrained eating, emotional eating and external eating subscales was high in the current study, Cronbach's $\boldsymbol{a}$ = 0.91 (DEBQ-R), Cronbach's $\boldsymbol{a}$ = 0.93 (DEBQ-Em) and Cronbach's $\boldsymbol{a}$ = 0.85 (DEBQ-Ex).

2.4 Data analysis

2.4.1 Pearson's correlation analysis

In order to assess consistency between self-control measures used in this study, Pearson's correlations were conducted to examine the relationship between different measures of self-control.

2.4.2 Univariate analysis of variance (ANOVA)

Subsequently, participants were divided into a low (N=38), average (N=39) or high (N=39) group based on each of their self-control measures (SST, ST-IAT and BSCS). A series of univariate analysis of variance (ANOVA) was then applied to examine whether food choice differed between the high, average and low self-control groups. This analysis was repeated with each of the tested self-control measures. Post-hoc t-tests

(Bonferroni-correction) were used for multiple comparisons to test individual differences in behavioural forced-choice responses between different self-control groups.

2.4.3 Hierarchical regression analysis

A hierarchical regression analysis was employed to investigate the effectiveness of different self-control measures for predicting food choice. Specifically, regression models were fitted to the dataset of the behavioural forced-choice responses (BFCR). For the regression analysis, BMI and hunger scores were entered at step 1 to give the baseline model. Implicit self-control, inhibitory control and explicit self-control were separately entered at step 2. All independent variables were standardised prior to applying regression analysis.

2.4.4 Moderation analysis

A hierarchical regression analysis was used to investigate the direct effect of self-control on food choice. The standardised regression coefficients (β) of these three self-control measures (BSCS, SST and ST-IAT) was compared for the prediction on food choice. The largest standardised regression coefficients of self-control measure (BSCS, SST or ST-IAT) will be selected for moderation analysis. Moderation analysis was conducted to assess the moderating role of self-control on the relationship between disinhibited eating and food choice. The moderation analysis is similar to the median split that can separate the continuous moderator (self-control) into high and low self-control groups (Hayes, 2013).

Moderation analysis was used to explore whether self-control moderated the relationship between disinhibited eating and behavioural forced-choice responses for individuals with low and high self-control (Muller et al., 2005). The moderation model (model 1) was conducted in a macro program (process v3.1) with 5000 bootstrap samples to estimate the predictors (trait self-control and disinhibited eating) and two-way interaction on the dependent variables (BFCR) in regression models (Hayes, 2013). In order to test the moderating effects of self-control (moderator), the two-way interaction effect of the self-control (moderator) multiplied by disinhibited eating (independent variable) was considered (Aiken, West, & Reno, 1991). The criteria of statistical significance for the moderating effect was approved when the CI did not include zero in the moderation analysis. The groups of the moderator were coded as -1 SD (low) and +1 SD (high), the computed slopes were created for these two groups. All continuous variables were mean-centred prior to applying moderated analysis.

Pearson's correlation analysis, univariate analysis of variance and moderation analysis was performed using SPSS 25 (BMI, Chicago, IL), the hierarchical regression analysis was carried out using JMP statistical package (SAS Institute, Cary, NC).

2.5 Results

2.5.1 Participants' characteristics

The basic measures of participants' characteristics were summarized in Table 2.1. A series of univariate analysis of variance (ANOVA) was carried out to examine the homogeneity between the three different self-control groups (*i.e.*, low, average and high), including age, BMI, hunger level, DEBQ-R and DEBQ-D. The results suggested that only DEBQ-D ($p < 0.001$) was significantly different, although the DEBQ-R (N.S) was trending significantly across the self-control groups defined by the BSCS. Post-hoc tests on BSCS self-control suggested that both the high self-control group (M = 2.79, SE = 0.10) ($p < 0.001$) and average self-control (M = 3.09, SE = 0.10) ($p = 0.004$) reported significantly less disinhibited eating tendency, compared to the low self-control group (M = 3.55, SE = 0.10). No other significant differences were presented.

Table 2.1 - Summary of descriptive statistics (mean and standard error) of the self-control and other measures obtained in the current study.

	Self-control measures											
	SST				**ST-IAT**				**BSCS**			
Participants' characteristics	Low (N=38)	Average (N=39)	High (N=39)	p-value	Low (N=38)	Average (N=39)	High (N=39)	p-value	Low (N=38)	Average (N=39)	High (N=39)	p-value
Age	22.47 (0.94)	22.85 (0.93)	23.85 (0.93)	0.563	22.87 (0.95)	23.82 (0.93)	22.49 (0.93)	0.581	22.32 (0.94)	23.00 (0.93)	23.85 (0.93)	0.512
BMI	23.09 (0.70)	23.42 (0.69)	23.48 (0.69)	0.913	24.02 (0.69)	22.40 (0.69)	23.59 (0.69)	0.232	24.01 (0.70)	22.98 (0.69)	23.02 (0.69)	0.496
Hunger	48.57 (4.25)	54.35 (4.20)	52.94 (4.20)	0.604	56.61 (4.19)	54.33 (4.14)	45.12 (4.14)	0.122	58.59 (4.20)	50.74 (4.14)	46.77 (4.14)	0.130
DEBQ-R	2.74 (0.14)	2.73 (0.14)	2.53 (0.14)	0.503	2.52 (0.14)	2.61 (0.14)	2.86 (0.14)	0.205	2.42 (0.14)	2.74 (0.14)	2.83 (0.14)	0.084
DEBQ-D	3.07 (0.11)	3.13 (0.11)	3.21 (0.11)	0.681	3.23 (0.11)	3.11 (0.11)	3.08 (0.11)	0.595	**3.55** (0.10)	**3.09** (0.10)	**2.79** (0.10)	**<0.001**

BMI = Body mass index; DEBQ-R= Dutch Eating Behaviour Questionnaire-Restrained eating; DEBQ-D= Dutch Eating Behaviour Questionnaire-disinhibited eating (the mean of the scores of Dutch Eating Behaviour Questionnaire-Emotional eating and External eating); SST = Stop signal task; ST-IAT=Single-target implicit association test; BSCS =Brief self-control scale.

2.5.2 Assessments of concordance across self-control measures

Pearson's correlation analysis applied to the self-control measures showed no significant result (SST vs. ST-IAT: r = 0.044, N.S; SST vs. BSCS: r = 0.014, N.S; ST-IAT vs. BSCS: r = 0.107, N.S), indicating that these three measures were not correlated to each other.

2.5.3 Differences in behavioural forced-choice responses to high-calorie food between self-control groups

The averaged measure of behavioural forced-choice responses across different self-control groups was displayed in Figure 2.5. ANOVA was employed to assess differences across the groups estimated by each type of self-control measures.

Notably, the analysis based on BSCS indicated a significant difference for behavioural forced-choice responses towards high-calorie food [$F_{(2,113)}$ = 6.797; p = 0.002]. A post-hoc test, based on a test of simple effects, suggested that the low self-control group (M = 5.95, SE = 5.76) reported significantly stronger preferences to high calorie food compared to the high self-control group (M = -22.30, SE = 4.99) (p = 0.001). However, no significant difference was found between low (M = 5.95, SE = 5.76) and average (M = -9.51, SE = 5.47) (N.S), nor between average (M = -9.51, SE = 5.47) and high (M = -22.30, SE = 4.99) (N.S) BSCS self-control group.

The same ANOVA was conducted for the ST-IAT self-control measure, the analysis indicated a significant difference for BFCR towards high-calorie food [$F_{(2,113)}$ = 4.364; p = 0.015]. The post-hoc test based on the test of simple effects suggested that the low self-control group (M = 3.91, SE = 5.71) reported significantly stronger preferences to high calorie food, compared to the high self-control group (M = -18.88, SE = 5.35) (p = 0.013). However, no significant difference was found between low (M = 3.91, SE = 5.71) and average (M = -10.95, SE = 5.51) (N.S), nor between average (M = -10.95, SE

= 5.51) and high (M = -18.88, SE = 5.35) (N.S) ST-IAT self-control groups.

In terms of the SST self-control measure, the ANOVA analysis based on SST indicated no significant difference for BFCR towards high-calorie food [$F_{(2,113)}$ = 0.357; N.S].

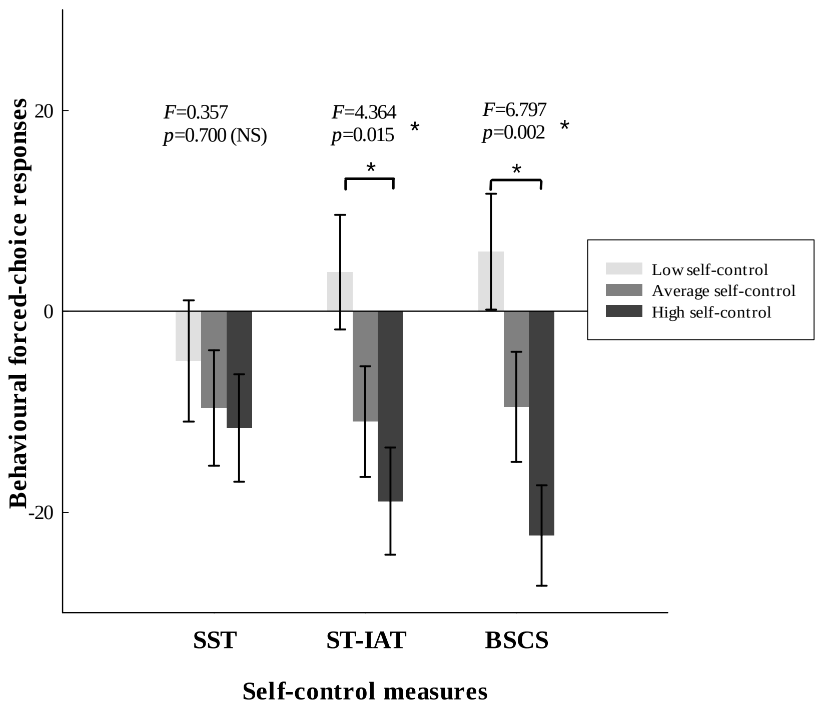

Figure 2.5 - Bar graphs of means (with standard errors) illustrating comparisons between low, average and high groups for three different self-control measures (SST, ST-IAT and BSCS) in terms of behavioural forced-choice responses for high- and low-calorie food.

SST = Stop signal task; ST-IAT=Single-target implicit association test; BSCS =Brief self-control scale.

2.5.4 Self-control measures in predicting food behavioural forced-choice responses

Results derived from the hierarchical regression analysis were summarised in Table 2.2. Regression analysis showed that there was no significant effect for both hunger [β = 0.143, t = 1.55, N.S] and BMI [β = 0.139, t = 1.51, N.S] control variables on the prediction of BFCR at step 1 [$F_{(2,\ 115)}$ = 2.25, N.S], which took up 3.8% of the total explained variance.

With regard to BSCS, the regression analysis revealed that BSCS emerged as a significant predictor for food behavioural forced-choice responses above the control variable [β = -0.269, = -2.90, p = 0.005] with higher levels of BSCS self-control being associated with a less preference for high-calorie foods. BSCS self-control significantly contributed to the additional 6.7% of the explained variance with a significant increase at step 2 [$\Delta F_{(3, 112)}$ = 4.40, p = 0.006].

ST-IAT emerged as a significant predictor on the prediction of BFCR above control variables [β = -0.248, t = -2.74, p = 0.007] at step 2 with higher levels of ST-IAT being associated with stronger preference for low-calorie food. Self-control significantly contributed to the additional 6.1% of the explained variance with a significant increase at step 2 [$\Delta F_{(3, 112)}$ = 4.10, p = 0.008].

SST was entered at step 2, the regression analysis revealed that there was no significant effect for SST on the prediction of BFCR above control variables, which accounted for a further 2.0% of the explained variance [β = -0.141, t = -1.53, N.S; $\Delta F_{(3, 112)}$ = 2.30, N.S].

Table 2.2 - Results from the hierarchical regression analysis using the inhibitory control, implicit self-control, explicit self-control on behavioural forced-choice responses for high- and low-calorie food. Significant F-statistics, standardised regression coefficients (β) and R square are highlighted in bold (*p* < or = 0.05).

Variables entered	β(step1)	β(step2A) SST	β(step2B) ST-IAT	β(step2C) BSCS
Hunger	0.14	0.15	0.11	0.09
BMI	0.14	0.15	0.14	0.09
		-0.14	**-0.25**	**-0.27**
R^2	0.03	0.06	**0.10**	**0.11**
ΔR^2	0.02	0.03	**0.07**	**0.08**
ΔF	2.25	2.30	**4.10**	**4.40**

BFCR= Behavioural forced-choice response; BMI = Body mass index; SST = Stop signal task; ST-IAT=Single-target implicit association test; BSCS =Brief self-control scale.

2.5.5 Moderation of self-control on the relationship between disinhibited eating and food behavioural forced-choice responses

The standardised regression coefficients of BSCS [β = -0.269] was larger than both SST [β = -0.141] and ST-IAT [β = -0.248] for prediction on food behavioural forced-choice response. Further data analysis was needed to explore whether explicit self-control moderated the relationship between disinhibited eating and their BFCR responses for individuals with low and high self-control. Moderation analysis (model 1) was conducted in PROCESS macro program with 5000 bootstrap samples to estimate the predictors (explicit self-control and disinhibited eating) and two-way interaction on the dependent variables (BFCR) in regression models (Hayes, 2013).

The predictor variables (explicit self-control and disinhibited eating) and the two-way interactions were regressed on the BFCR, showing that the overall regression model [$F_{(3, 112)}$ = 5.07, p < 0.001, R^2 = 0.17] was significant. Moderation analysis showed that both disinhibited eating [B = 13.88, $t_{(112)}$ = 2.73, p = 0.007] and BSCS [B = -10.55, $t_{(112)}$ = -1.99, p = 0.049] significantly predicted BFCR towards high-calorie foods and the two-way interaction [B = 9.73, $t_{(112)}$ = 5.80, p = 0.096] had a marginally significant effect on BFCR for high-calorie foods. The associated 95% confidence intervals of the estimated conditional effects for high self-control (7.85, 32.74) did not contain zero (Table 2.3). This indicated self-control moderated the relationship between disinhibited eating and BFCR such that a positive relationship was observed in those with high self-control [B = 20.30, $t_{(112)} = 3.23$, $p = 0.002$], but no relationship was observed in those with low self-control [B = 7.47, $t_{(112)} = 1.16$, N.S].

Table 2.3 - Conditional effects of explicit self-control on the relationship between disinhibited eating and behavioural forced-choice responses for high- and low-calorie food at low and high self-control.

	Self-control	Conditional effect	
	BSCS	Coefficient estimate (SE)	95% CI
BFCR	Low	7.47 (6.45)	-5.32, 20.25
	High	**20.30 (6.28)** [b]	**7.85, 32.74**

BFCR= Behavioural forced-choice responses; BSCS =Brief self-control scale; DEBQ-D= Dutch Eating Behaviour Questionnaire-disinhibited eating (the mean of the scores of Dutch Eating Behaviour Questionnaire-Emotional eating and External eating).

[a] $p < 0.05$; [b] $p < 0.01$.

The self-control groups of the moderator were coded as -1 SD (low) and +1 SD (high) for BFCR (Figure 2.6), the computed slopes were created for these two groups as recommended by Muller et al. (2005). The estimated conditional effects of self-control on the relationship between disinhibited eating and food behavioural forced-choice responses was 20.30 for high self-control.

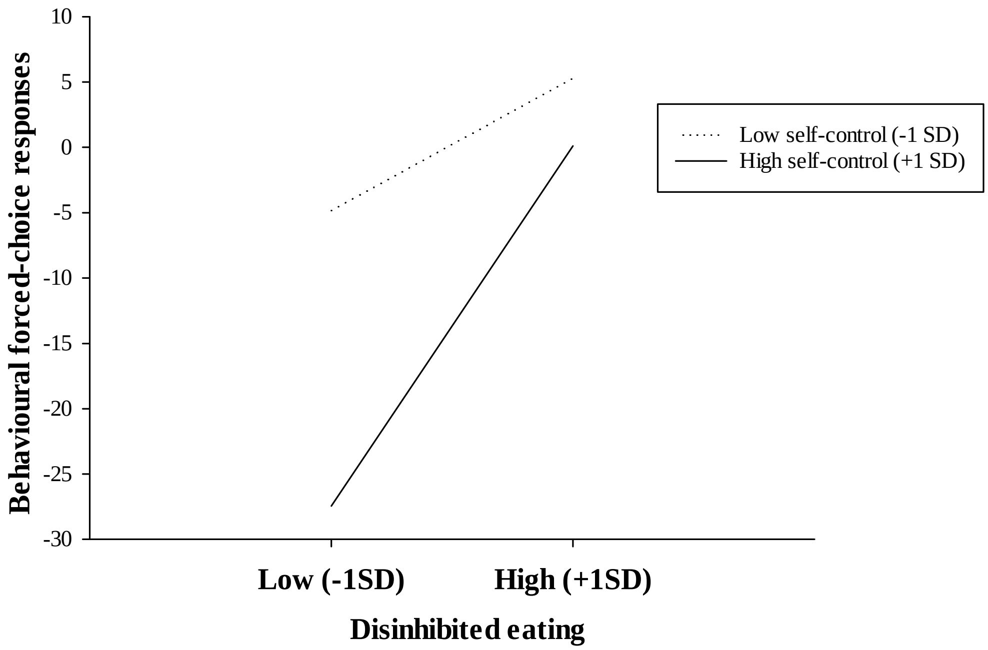

Figure 2.6 - Line graphs of means illustrating the moderation effect of the relationship between disinhibited eating and behavioural forced-choice responses by explicit self-control at low and high groups.

2.6 Discussion

The present study assessed relationships between an individual's inhibitory control, implicit/explicit self-control abilities and their choices of palatable food. Specifically, the study examined whether self-inhibitory or self-control measures can predict an individual's behavioural forced-choice responses for high-calorie food (HCF) and low-calorie food (LCF). Findings from the study suggested a poor concordance across these common self-control measures. In addition, significant relationships between self-control and food behavioural forced-choice responses were observed–both explicit and implicit self-control measures successfully predicted the behavioural forced-choice responses to high-calorie food (HCF). Furthermore, explicit self-control moderated the relationship between disinhibited eating and behavioural forced-choice responses to high-calorie food (sweets) such that a positive relationship was observed in individuals with high self-control.

2.6.1 The concordance across these common self-control measures

The current study was the first to investigate the association between the commonly used self-control measures – inhibitory, implicit and explicit self-control – in the context of food choice. In general, findings from the study suggested self-inhibitory did not correlate with both implicit and explicit self-control. According to the self-inhibitory systematic review, the stop signal task assesses an individual's ability to inhibit the improper motor response (Bartholdy et al., 2016). Accordingly, it has been indicated that poor performance in this task is a liability for impulsivity (Bari & Robbins, 2013). Implicit and explicit self-control measures highlight the role of impulsive and reflective systems (Strack & Deutsch, 2004). These findings indicate that measurements of the SST are not constructed the same as implicit and explicit measures of self-control and add to an understanding of why there is no association between them. This is in line with the previous study that indicated inhibitory control was not found to correlate with explicit measures of self-control (Allom et al., 2016).

Findings from the current study suggested no association between the implicit and explicit self-control measures, adding to the existing evidence for the reflective (*i.e.* explicit) and impulsive (*i.e.* implicit) systems (Hofmann et al., 2009; Keatley et al., 2017; Strack & Deutsch, 2004). While the present finding is in line with the majority of previous research (Huntjens et al., 2014), a few studies found contrasting results. For instance, Keatley et al. (2017) observed a significant negative correlation between the explicit and implicit self-control in their study of the role of self-control in aggressive tendencies. The inconsistent finding from Keatley et al. (2017) might be attributed to the effect of social desirability, as the participants could be exposed to the research question prior to assessments of self-control, given the randomisation employed in this study. Therefore, this inconsistency has motivated further exploration for the reliability of ST-IAT. In future studies, it would be useful to determine internal reliability and validity of the ST-IAT on implicit self-control by using a larger sample size.

Another possible reason to explain the lack of the association among these self-control measures may be low reliability of reaction time tasks (*e.g*. stop-signal task and implicit association task). According to the latest research on assessing the reliability of seven commonly used cognitive tasks (*e.g*. stop signal and Stroop) in three empirical studies, the results suggested reaction time tasks have notoriously low reliability (Hedge, Powell, & Sumner, 2018). This may limit the likelihood that self-control measures – inhibitory, implicit and explicit self-control would correlate with other individual differences (Hedge et al., 2018).

2.6.2 The effectiveness of self-control measures in predicting food behavioural forced-choice responses

The current study found that explicit self-control was the most effective approach to significantly predict behavioural forced-choice responses for low-calorie foods (*e.g.* fruits). Previous research that assessed explicit self-control and food consumption has produced a mixture of findings. While some studies observed that explicit self-control has little effect on snack intake and alcohol consumption (Friese & Hofmann, 2009; Haynes et al., 2014), others found that explicit self-control can predict consumption of healthy food (*e.g.* fruits) (Giese et al., 2015; Hankonen, Kinnunen, Absetz, & Jallinoja, 2013). Findings from the current study corroborate the latter with higher levels of explicit self-control being associated with higher behavioural forced-choice responses for low-calorie foods (*e.g.* fruits). This has proved that the positive impacts of effective self-control are evident in healthy eating (Sproesser et al., 2011), such as fruit and vegetable consumption (Wills et al., 2007).

Results from the present study suggest that the implicit self-control measure successfully predicts the behavioural forced-choice responses to high-calorie foods. As previous studies suggest, implicit measures are more sensitive to automatic behaviour triggered by high temptation (Asendorpf, Banse, & Mücke, 2002; DeCoster, Banner, Smith, & Semin, 2006; Smith & DeCoster, 2000; Strack & Deutsch, 2004). Specifically, individuals with a higher estimate of implicit self-control had less HCF choice. This predicted relationship is consistent with findings from a previous study whereby individuals with high self-control are more resistant to impulses elicited by temptation-related stimuli (Fishbach & Shah, 2006). Effective self-control in high self-control individuals consists of proactively adopting strategies to avoid the possibility of conflict, rather than adopting conscious conflict-inhibiting behaviour after the conflict has emerged (Fujita, 2011).

In general, findings from the study added to the existing evidence for the dual processes in the context of food choice, as described by the reflective and impulsive system (Hofmann, Friese, & Wiers, 2008; Strack & Deutsch, 2004). For the reflective system, results from the present study suggested that the explicit self-control successfully predicted behavioural forced-choice responses for low-calorie foods (***e.g.*** fruits). Specifically, individuals with a higher estimated of self-control showed increased food choices for low-calorie foods. For the impulsive system, results from the present study suggested that implicit self-control measure successfully predicts the behavioural forced-choice responses to high-calorie foods. Specifically, individuals with a higher estimated of self-control showed decreased food choices for high-calorie foods. In this study, low-calorie foods are used as the stimulus of a lower temptation, which is more likely to activate deliberate behaviour. As previous studies suggested, the impulsive system is more sensitive to unconscious behaviour triggered by high-calorie foods, whereas reflective system can better predict deliberate and conscious behaviour (Asendorpf, Banse, & Mücke, 2002; DeCoster, Banner, Smith, & Semin, 2006; Smith & DeCoster, 2000; Strack & Deutsch, 2004). When LSCS and HSCS presented simultaneously in behavioural forced-choice responses task, both systems work together for determining the food choice, which added to the existing evidence for the dual processes (Strack & Deutsch, 2004).

Similar to the explicit self-control measure, findings from the current study also suggest that the self-inhibitory control measured by SST were unable to predict behavioural forced-choice responses to high-calorie foods. This is in line with a previous study that assessed the relationship between SST measures and chocolate preference (Papachristou, Nederkoorn, Beunen, & Jansen, 2013). According to a recent systematic review on uses of SST measures for predicting food intake, the majority of empirical studies found negative results (Bartholdy et al., 2016). Only two studies have been reported that successfully used SST to predict food intake. One study found that SST could successfully predict sugar consumption in preschool children, poorer SST performance of children was associated with higher sugar intake (Levitan et al., 2015). Another study indicated that participants with a poorer SST performance bought (in a virtual supermarket) more calories in total than participants with a better SST performance (Nederkoorn, 2014). This was only under a promotion condition in the overweight group and not in the normal-weight group. This suggests that the SST influences the amount of calories purchased for unhealthy groups, but not for healthy adults (Nederkoorn, 2014). Therefore, the effectiveness of SST measures for predicting food intake may only relate to the specific population. This inconsistency has motivated further exploration into the predictive reliability of the SST.

2.6.3 Moderation role of explicit self-control on the relationship between disinhibited eating and food behavioural forced-choice responses

Data from the current study showed that explicit self-control moderated the relationship between disinhibited eating and food behavioural forced-choice responses. Specifically, the results suggest that explicit self-control moderated the relationship between disinhibited eating and BFCR to high-calorie foods (sweets) such that a positive relationship was observed in individuals with high self-control. This is consistent with findings from a previous study whereby high self-control individuals are good at inhibiting impulses elicited by temptation-related stimuli (Fishbach & Shah, 2006). Successful self-controllers are more aware of their weight control goals when they are exposed to palatable foods, and they can successfully resist the need for instant gratification in order to achieve their long-term weight management goals (Hofmann et al., 2008). However, an unsuccessful self-controller fails to control themselves due to the relative superiority of wanting the instant gratification associated with tempting objects (Gillebaart & Ridder, 2015), which has been explained by the goal-conflict model (Stroebe, Mensink, Aarts, Schut, & Kruglanski, 2008). Self-control processes are likely to be automatically triggered by tempting objects for these successful self-controllers because they had previous experiences in being able to resist temptations (Fishbach et al., 2003). Therefore, it may be easy for them to avoid the temptation to achieve weight control goals (Büttner et al., 2014), a finding which is supported by Hofmann, Baumeister, et al. (2012), who found that individuals with high self-control had a less motivational conflict and are better at avoiding temptations.

2.6.4 Hunger in influencing eating behaviour

The current study revealed that hunger had no relationship with food choice. Previous studies have shown that the effect of hunger on eating behaviour has produced a mixture of findings. While some studies have shown that hunger as a physiological factor has an effect on the amount of food individuals' purchase and consume (Mela, Aaron, & Gatenby, 1996; Nisbett & Kanouse, 1969) especially in meal initiation (Stubbs et al., 2000), other studies have shown no relationship between energy intake and hunger level (Fay et al., 2015). Findings from the current thesis corroborate the latter with no association between hunger and food choice. Which is true in many situations such as binge eating, people eat when they are not hungry (Fay et al., 2015). This is the current study expected. Participants eat without hunger may reflect a low level of self-control; low self-control individuals are more susceptible to snacking behaviour (Adriaanse et al., 2014). Unsuccessful self-control is more likely to occur for low self-control individuals because they are attracted to instantaneous satisfaction due to the reward of high energy density food (HEDF) (Gillebaart & Ridder, 2015).

2.7 Limitations

A limitation of the present study is that only one type of food (*i.e.* sweet food) was used for this study. Previous studies of food choice suggest that the decision-making process of food choice can vary considerably across food types (*i.e.*, desserts vs. main meals) (Graham, Hoover, Ceballos, & Komogortsev, 2011; Wang, Cakmak, & Peng, 2018). Future research should replicate the current findings with other food types, using different eating scenarios.

2.8 Conclusion

The current chapter adds important insights into the role of self-control in food choice. Specifically, the results of the current chapter showed (1) no correlation between different measures of self-control, suggesting these different measures reflect different self-control processes; (2) both explicit and implicit self-control, assessed by a BSCS and ST-IAT respectively, can predict food behavioural forced-choice responses to high-calorie foods. As such, it usefully contributes to the current knowledge of dual systems of self-control in food choice; and (3) that explicit self-control moderated the relationship between disinhibited eating and food behavioural forced-choice responses to high-calorie food (sweets) such that a positive relationship was observed in individuals with high self-control. Future research could apply explicit self-control measures in assessing different food types, associated with different tastes, in order to attain a better understanding of the relationship between explicit self-control and food choice.

Chapter 3: Assessing the role of self-control in different eating scenarios

3.1 Summary

The inconsistencies in the literature between disinhibited eating and food intake could be related to the lack of consideration given to the bottom-up food reward and top-down impulse control processes. Hence more research is needed to unravel the mechanism of inter-individual differences in this relationship. The current study assessed the role of self-control in different eating scenarios. Specifically, a total of 61 participants, identified with either high or low self-control, were tested for their food consumption for three categories of food (*i.e.*, two similar energy density of chips, ice cream and pasta) in three *ad libitum* sessions. Results derived from hierarchical regression showed that explicit self-control had no direct effect on food energy intake across three eating scenarios. Mediation analysis suggested chips liking only mediated the relationship between disinhibited eating and chips energy intake. Furthermore, self-control moderated the relationship between disinhibited eating and chips energy intake via liking such that a positive relationship was observed in those with low self-control. In addition, self-control moderated the relationship between disinhibited eating and ice cream energy intake such that a negative relationship was observed in individuals with high self-control, but no such moderating role of self-control was observed in the pasta eating scenario. This study added important insights into the top-down and bottom-up processes, namely that the moderating role of self-control on food energy intake can vary considerably across food types.

3.2 Introduction

The expectation that high energy density palatable foods will be rewarding has been associated with overconsumption in previous research (Combs, Smith, & Simmons, 2011; Hennegan, Loxton, & Mattar, 2013). Food rewards have been suggested to relate to many dimensions, one of the most important being food liking (Horner et al., 2016). The food choices in people's daily life are primarily based on food preferences that are pleasure-driven (Blundell, Dalton, & Finlayson, 2013). Hedonic-driven eating has attracted the attention of many researchers, especially in the "eating behaviour" field. Previous studies have demonstrated that enhanced liking for a specific food leads to increased susceptibility to overeating (Finlayson & Dalton, 2012). Further studies have examined the process of liking in food reward, which may help appetite control and weight regulation (Finlayson et al., 2008; Finlayson, King, & Blundell, 2007). Rewarding sensory properties of palatable food, related to the positive affect, triggers an approach behaviour (Chen & Bargh, 1999; Cohen & Farley, 2008; Duckworth et al., 2002; Ferguson & Bargh, 2013). However, an individual's ability to resist these high energy density palatable foods varies greatly with the different levels of control resources (Hall, Lowe, & Vincent, 2014; Hofmann et al., 2008; Wang et al., 2015).

Prior studies that have assessed the effect of explicit self-control on food consumption have observed conflicting findings. Some studies revealed that explicit self-control has no influence on potato chips intake (Friese & Hofmann, 2009), chocolate consumption (Wang et al., 2015), amount of cookies eaten (Hagger et al., 2013), sweet pastry consumption frequency (Robinson et al., 2016), vice and virtue food choice (cake versus fruit salad) (Haws, Davis, & Dholakia, 2016a). However, other studies indicated that explicit self-control was observed to be significantly related to fruit and vegetable consumption (Giese et al., 2015), sugar-sweetened soda consumption frequency (Robinson et al., 2016), vice and virtue food choice (French fries versus side salad; M&Ms versus raisins) (Haws, Davis, & Dholakia, 2016a). Inconsistent findings may be different eating scenarios were created. Self-control conflict can be successfully triggered or not may vary in the different eating scenarios. Therefore, further validation of the role of explicit self-control in different eating scenarios is important.

Previous studies suggest that individuals who display high disinhibited eating behaviours were more likely to have a higher intake of chocolate cookies and savoury crackers (Ouwens et al., 2003a, 2003b). However, other studies have pointed out that there is no association between disinhibited eating and milk products such as ice cream and milkshakes (Ouwens et al., 2007; Van Strien et al., 2000). Inconsistencies related to disinhibited eating and food consumption in literature may be due to the fact that the disinhibition effect on the food intake was not triggered. Emerging data have suggested that two distinguishable processes determine food intake, the top-down (*i.e.* deliberate) impulse control and the bottom-up (*i.e.* impulsive) food reward processes (Gerlach et al., 2015; van der Laan & Smeets, 2015). Particularly for the bottom-up process, liking elicited by food is a primary driver of eating (Blundell, Dalton, & Finlayson, 2013; Horner et al., 2016). For the top-down process, self-control has also been suggested to be a critical factor for regulating eating behaviour (Metcalfe & Mischel, 1999). One of the hypotheses is the inconsistencies in the relationship between disinhibited eating and food intake could be related to overlooking bottom-up and top-down processes. Hence more research is clearly needed to unravel the role of liking and self-control in this relationship.

The current study aimed to assess the role of self-control in different eating scenarios. Specifically, this study was designed to investigate 1) the effect of explicit self-control on different food energy intake 2) Whether liking mediated the relationship between disinhibited eating and food energy intake 3) Whether self-control moderated the relationships between disinhibited eating, liking and food energy intake across different food types. Findings from this study provided more understandings about the role of self-control in food energy intake, which offered important insights into bottom-up and top-down mechanisms in different eating scenarios.

3.3 Methods

3.3.1 Participants

Food familiarity is a key factor that affects food intake (Brunstrom, Shakeshaft, & Scott-Samuel, 2008). Thus, to ensure the participants have a similar level of familiarity with the food used in this study, participants only includes individuals who were either born in NZ or have resided in NZ for at least 10 years. In addition, to ensure the measurement of food intake is not confounded by food allergens and food restrictions, this study only includes participants, who are able to consume food that may contain gluten, soy, meat, wheat, dairy, and eggs. Participants, who are vegetarians or under diet program, were excluded because their responses can be potentially biased the data. The inclusion criteria were healthy individuals between the age of 18 and 50 years, regular individuals of chips, ice cream and pasta (***i.e.*** consume all these foods at least once per month). For this study, participants were predominantly recruited by flyers posted on notice boards across the University of Otago campus and its surrounding areas. In addition, a recruiting email was sent to different departments, and the study was also advertised on social media (***e.g.*** Facebook).

Before the study started, participants were asked to complete an online screening questionnaire, confirming eligibility to participate in the current study. In total, 66 females were recruited based on prior screening procedures to exclude those participants who were currently taking regular medication and did not meet eligibility. Finally, 61 of them completed this study (M_{age} = 23.95; SD = 5.6; Range:18-47). On par with previous research, the current study focused on female participants only (Weingarten & Elston, 1991). Ethical approval for this study was granted by the Human Ethics Committee of the University of Otago (Reference number: 18/101). Participants who meet the criteria were asked to attend three sessions (30-minutes each) with at least one-day apart between each session, they were tested between 8:00 and 13:00h in a standard sensory facility equipped with a Windows OS system computer, 14-inch monitor, Mac Magic keyboard and Sennheiser HD 202 headphone. All participants were asked to consume a standardised breakfast of porridge with milk in the morning, then they were asked to abstain from any food or non-water beverage for two hours before the chips and ice cream sessions or five hours before the pasta session. An informed consent was completed before the experiment. All participants were entered into a draw with a chance to win one out of three $100 supermarket vouchers.

3.3.2 Food stimuli

The Food stimuli used in the current study consisted of 3 food categories. The types of food and their categories (Kcal per 100g reported in Table 3.1) were: Chips- Bluebird Sour Cream & Chives (526 Kcal) and Chicken (511 Kcal), Ice Cream-Tip Top Chocolate (204 Kcal) and Vanilla (206 Kcal), Pasta Bolognese (1312 Kcal) and Carbonara (1313 Kcal). Both chips and ice cream were commercially available. The pasta was prepared in the department's food lab and served at 65 °C. To ensure the serving temperature of pasta, a water bath heating system was set up with a 90 ℃ temperature measuring scale. The pasta's calorie content was calculated using Foodworks (version 9; Xyris software, Australia).

Table 3.1 - List of the food stimuli and its energy density (Kcal/100g) used in the current study.

Food category	Food Name	Energy Density (Kcal/100g)
Chips	Bluebird Sour Cream & Chives	526
	Bluebird Chicken	511
Ice cream	Tip Top Chocolate	204
	Tip Top Vanilla	206
Pasta	Pasta Bolognese	1312
	Pasta Carbonara	1313

3.3.3 Procedure

Upon arrival, participants were given an oral introduction about the study, along with the presentation of an information sheet 1 for the participant (Appendix 5). Once they had agreed to participate, they were asked to give written consent (Appendix 6-Consent form 1).

The first two 30-minutes sessions consisted of one hunger level check task, one hedonic response task and one food consumption task. In the first two 30-minute sessions, participants were asked to perform a hunger level check task followed by a hedonic responses task. Participants were then instructed to conduct a food consumption task with a 20-minute movie. The third session repeated the same tasks in the first two sessions with additional questionnaires. Participants were asked to complete a self-control task for measuring an individual's self-control followed by The Dutch Eating Behaviour Questionnaire (DEBQ) (Figure 3.1). Upon the completion of the study, participants' height and weight were measured to calculate Body Mass Index (BMI; kg/m^2). All response data were collected by Qualtrics© (USA, 2016). At the end of the study, participants were brief about the study with informing the purpose of this study, along with the presentation of an information sheet 2 for the participant (Appendix 7), they were asked to complete a consent form 2 about whether the data about food intake can be used or not (Appendix 8). The full research objectives were only be enclosed at the end of the study (end of Session 3) along with the presentation of an information sheet 2 for the participant (Appendix 7). The reason to deceive the research aim of this study at the early stage is to prevent the bias of the data collected from participants.

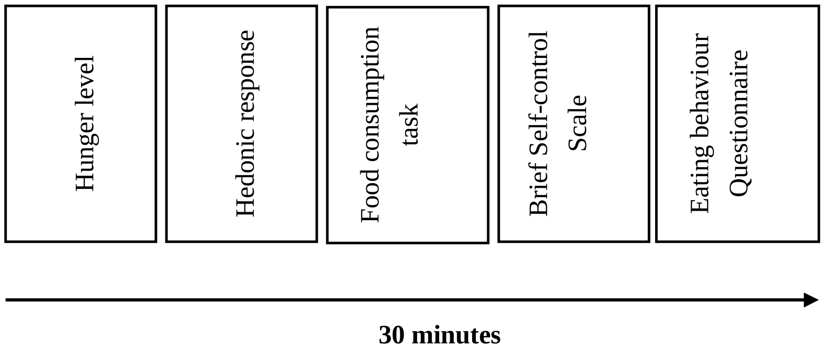

Figure 3.1 - An outline of the experimental events (according to time and order) and the various tasks for session 3.

Hunger level

Participants were instructed to check their hunger level on a 100-mm *Visual Analogue Scale* (*VAS*) (refer to section 2.3.3; page 41).

Hedonic response task

The liking for each type of food on three tested categories (chips, ice cream and pasta) was measured by using a 100-mm *Visual Analogue Scale* (*VAS*) anchored from “Not at all” (0) to “Extremely” (100). Participants were presented with each type of food from three tested categories, in a randomized order, across three different sessions. They were instructed to rate “How much do you like this food?” on the VAS scale before food consumption. The mean scores of hedonic responses for a category were calculated by averaging the rating scores of each food stimuli, within that category, for each subject’s response. A higher score denotes a higher liking for that category.

Food consumption task

The food consumption task was set up to measure food energy intake. The weights of each type of food were Chips- Bluebird Sour Cream & Chives (140g; SD = ±0g) and Chicken (140g; SD = ±0g), Ice Cream-Tip Top Chocolate (200.10g; SD = ±0.12g) and Vanilla (200.12g; SD = ±0.12g), Pasta Bolognese (500.31g; SD = ±0.22g) and Carbonara (500.33g; SD = ±0.25g). All tested products were presented in a big porcelain bowl labelled with the participant ID under the bowl. To prevent the ice cream from melting, they were placed into a plastic bowl surrounded by ice. Participants were given a plate and asked to select any type of food for a 20-minute movie, they can select as much as they would like to eat. After food selection, their food choice in the plate was weighed. Participants were asked to sit in a sensory booth, equipped with a computer screen and a pair of headphones. Then all types of food were moved into the sensory booth next to participants. They were instructed to watch a 20-minutes non-food related documentary. The duration of the movie was decided based on each type of food consumption time in the pilot test. They received the instruction as “Please pay full attention to this film, you will be asked some questions about this film after”. During the film, participants were asked to consume the food ***ad libitum***, they could refill the plate until the movie ended. After 20 minutes, their leftover was also weighed. The food energy intake of each category was calculated. For each participant, three categories of food were presented counterbalanced over different sessions.

Brief self-control scale

Explicit self-control was measured by Tangney’s Brief Self-Control Scale (BSCS) (Maloney et al., 2012; Tangney et al., 2004) on a 5-point Likert scale (refer to section 2.3.3; page 43). The internal consistency coefficient alpha for BSCS scale was Cronbach’s ***a*** = 0.78 in the current study.

Eating behaviour questionnaire

Restrained eating (DEBQ-R), Emotional eating (DEBQ-Em) and External eating (DEBQ-Ex) subscales of the Dutch Eating Behaviour Questionnaire (DEBQ) were used to assess eating behaviour tendencies (Van Strien et al., 1986b) (refer to section 2.3.3; page 44-45). The internal consistency coefficient alpha for restrained eating, emotional eating and external eating subscales was Cronbach’s ***a*** = 0.89 (DEBQ-R), Cronbach’s ***a*** = 0.91 (DEBQ-Em) and Cronbach’s ***a*** = 0.76 (DEBQ-Ex) in the current study, respectively.

3.4 Data analysis

Food energy for these foods was calculated using the nutrition panel calculator developed by Food Standards Australia New Zealand. Energy intake was defined by the total energy intake of food consumed in the plate (Kcal), which was calculated as the amount of food (gram) multiplied by the energy density (Kcal/gram) of that food.

3.4.1 Pearson's correlation analysis

Pearson's correlation analysis was conducted to examine the relationship between explicit self-control, hedonic responses, disinhibited eating and food energy intake together with the mean scores and standard deviations of these variables. The same analysis was applied to three different eating scenarios.

3.4.2 Hierarchical regression analysis

A hierarchical regression analysis was employed to investigate the direct effect of explicit self-control on food energy intake across different eating scenarios. Specifically, regression models were fitted to the dataset of chips, ice cream and pasta energy intake, respectively. For the regression analysis, hunger level and BMI were entered at step 1 to give the baseline model. Explicit self-control was entered at step 2. All independent variables were standardised prior to application of the regression analysis.

3.4.3 Mediation analysis

Mediation analysis (model 4) was used to test the hypothesis that whether liking (mediator variable) mediated the relationship between disinhibited eating (independent variable) and food energy intake (dependent variable) across different food types. Three separate regression models were tested by regressing (1) disinhibited eating (independent variable) on liking (mediator variable), (2) both disinhibited eating (independent variable) and liking (mediator variable) on food energy intake (dependent variable) and (3) disinhibited eating (independent variable) on food energy intake (dependent variable) (Baron & Kenny, 1986). In order to identify whether the criteria of the mediator were significant or not, the lower and upper limits of a 95% confidence interval (CI) were calculated by PROCESS (V3.1) macro program based on a bias-corrected bootstrapping method. The criteria of statistical significance for mediating effect was approved when the CI did not include zero.

3.4.4 Moderation analysis

Moderation analysis was used to explore whether self-control moderated the relationship between disinhibited eating and food energy intake for individuals with low and high self-control (Muller et al., 2005). A moderation model (model 5) was conducted in PROCESS program with 5000 bootstrap samples to estimate the predictors (explicit self-control and disinhibited eating) and a two-way interaction on the dependent variables (food energy intake) in regression models (Hayes, 2013). In order to test the moderating effects of self-control (moderator), the two-way interaction effect of self-control (moderator) multiplied by disinhibited eating (independent variable) was considered (Aiken et al., 1991). The criteria of statistical significance for the moderating effect was approved when the CI did not include zero in the moderation analysis.

3.4.5 Moderated-mediation analysis

Moderated-mediation analysis was used to explore whether liking mediated the relationship between disinhibited eating and food energy intake for individuals with low and high self-control across different food types (Muller et al., 2005). Moderated-mediation model (model 14) was conducted in the PROCESS program with 5000 bootstrap samples to estimate three separate pathways of regression models (Hayes, 2013) (1) the effect of disinhibited eating (independent variable) on liking (mediator variable), (2) the effect of liking (mediator variable) on food energy intake (dependent variable) and (3) the effect of disinhibited eating (independent variable) on food energy intake (dependent variable). In order to test the moderating effects of self-control (moderator), the interaction effects of self-control (moderator) multiplied by liking (mediator variable) in all models were considered. The criteria of statistical significance for the moderating effect was approved when the CI did not include zero in the moderated-mediation analysis.

Pearson's correlation analysis, mediation analysis, moderation analysis and moderated-mediation analysis were performed using SPSS 25 (BMI, Chicago, IL). The hierarchical regression analysis was carried out using the JMP statistical package (SAS Institute, Cary, NC). All continuous variables were mean-centred prior to application of mediation, moderation and moderated-mediation analysis.

3.5 Results

3.5.1 Participants' characteristics

Table 3.2 summarises the descriptive statistics of participants' characteristics. A series of Paired-Samples t-tests were performed to assess the homogeneity between these two self-control groups (median split, *i.e.*, low and high), including energy intake, liking, hunger, age, BMI, DEBQ-R and DEBQ-D. No significant difference was obtained.

Table 3.2 - Summary of descriptive statistics (mean and standard error) of the self-control and other measures obtained in the current study.

	Chips Session			**Ice cream session**			**Pasta session**		
N=61	**Self-control groups**			**Self-control groups**			**Self-control groups**		
Participants' characteristics	Low (N=31)	High (N=30)	p-value	Low (N=31)	High (N=30)	p-value	Low (N=31)	High (N=30)	p-value
Energy intake	474.97 (35.15)	459.52 (35.73)	0.759	362.62 (36.91)	353.37 (37.52)	0.861	1386.12 (81.97)	1377.25 (83.33)	0.940
Liking	72.95 (3.46)	69.73 (3.52)	0.517	73.63 (3.75)	73.43 (3.81)	0.971	80.50 (2.72)	81.80 (2.77)	0.739
Hunger	49.74 (3.66)	46.73 (3.72)	0.566	45.10 (3.44)	41.03 (3.49)	0.410	85.29 (2.62)	83.23 (2.66)	0.584
Age	24.42 (1.01)	23.47 (1.03)	0.511	24.42 (1.01)	23.47 (1.03)	0.511	24.42 (1.01)	23.47 (1.03)	0.511
BMI	24.19 (0.74)	22.27 (0.76)	0.068	24.19 (0.74)	22.27 (0.76)	0.068	24.19 (0.74)	22.27 (0.76)	0.068
DEBQ-R	2.21 (0.14)	2.54 (0.15)	0.107	2.21 (0.14)	2.54 (0.15)	0.107	2.21 (0.14)	2.54 (0.15)	0.107
DEBQ-D	3.16 (0.10)	3.06 (0.10)	0.479	3.16 (0.10)	3.06 (0.10)	0.479	3.16 (0.10)	3.06 (0.10)	0.479

BSCS =Brief self-control scale; DEBQ-R= Dutch Eating Behaviour Questionnaire-Restrained eating; DEBQ-D= Dutch Eating Behaviour Questionnaire-disinhibited eating (the mean of the scores of Dutch Eating Behaviour Questionnaire-Emotional eating and External eating); Body Mass Index (BMI; kg/m^2).

Notes: all participants attended three sessions, energy intake, liking and hunger was tested for three times across these three sessions (chips, ice cream and pasta), other measures (BSCS, age, BMI, DEBQ-R and DEBQ-D) was tested once at the end of the study (pasta session).

3.5.2 Relations between study variables

For the chip's session, correlation analyses showed that chips liking positively correlated to hunger levels (*r* = 0.321, *p* = 0.012), chips energy intake (*r* = 0.386, *p* = 0.002) and disinhibited eating (*r* = 0.348, *p* = 0.006) (Table 3.3).

Regarding the ice cream session, correlation analyses showed that ice cream liking was only positively correlated with ice cream energy intake (*r* = 0.430, *p* = 0.001).

In terms of the pasta session, pasta liking was positively associated with hunger level (*r* = 0.376, *p* = 0.003) and pasta energy intake (*r* = 0.361, *p* = 0.004). Furthermore, correlation analyses indicated that hunger levels were positively correlated with disinhibited eating (*r* = 0.409, *p* = 0.001).

Furthermore, BMI was found to be positively associated with disinhibited eating (*r* = 0.336, *p* = 0.008) and negatively related to explicit self-control (*r* = -0.273, *p* = 0.033). No other significant differences were presented.

Table 3.3 - Pearson's correlation coefficients between explicit self-control, hedonic response, disinhibited eating, hunger level and BMI in chips, ice cream and pasta sessions.

	Chips session								
	HBCS	CL	CEI	DEBQ-R	DEBQ-D	BSCS	BMI	Mean	SD
HBCS	—							48.26	20.25
CL	0.**32**[a]	—						71.37	19.19
CEI	-0.14	**0.39**[b]	—					467.37	194.22
DEBQ-R	0.09	0.05	0.14	—				2.37	0.81
DEBQ-D	0.21	**0.35**[b]	0.08	0.22	—			3.11	0.55
BSCS	-0.09	-0.16	-0.09	0.22	-0.23	—		2.99	0.58
BMI	-0.17	0.02	0.18	0.10	**0.34**[b]	**-0.27**[a]	—	23.22	4.23

Ice cream session									
	HBICS	ICL	ICEI	DEBQ-R	DEBQ-D	BSCS	BMI	Mean	SD
HBICS	—							43.10	19.08
ICL	-0.02	—						73.53	20.68
ICEI	-0.12	**0.43[b]**	—					358.07	203.83
DEBQ-R	-0.15	-0.10	-0.09	—				2.37	0.81
DEBQ-D	-0.11	0.19	0.09	0.22	—			3.11	0.55
BSCS	-0.18	0.02	-0.08	0.22	-0.23	—		2.99	0.58
BMI	-0.25	0.15	0.19	0.10	**0.34[b]**	**-0.27[a]**	—	23.22	4.23

Pasta session									
	HBPS	PL	PEI	DEBQ-R	DEBQ-D	BSCS	BMI	Mean	SD
HBPS	—							84.28	14.51
PL	**0.38[b]**	—						81.14	15.04
PEI	-0.10	**0.36[b]**	—					1381.76	452.6
DEBQ-R	0.06	0.02	-0.13	—				2.37	0.81
DEBQ-D	**0.41[b]**	0.24	0.16	0.22	—			3.11	0.55
BSCS	-0.04	-0.02	-0.11	0.22	-0.23	—		2.99	0.58
BMI	-0.04	0.12	0.19	0.10	**0.34[b]**	**-0.27[a]**	—	23.22	4.23

HBCS=Hunger before chips session; CL=Chips liking; CEI=Chips energy intake; HBICS=Hunger before ice cream session; ICL=Ice cream liking; ICEI=Ice cream energy intake; HBPS=Hunger before pasta session; PL=Pasta liking; PEI=Pasta energy intake; DEBQ-D= Dutch Eating Behaviour Questionnaire-disinhibited eating (the mean of the scores of Dutch Eating Behaviour Questionnaire-Emotional eating and External eating); BSCS =Brief self-control scale; Body Mass Index (BMI; kg/m^2).

Notes: all participants attended three sessions, energy intake, liking and hunger was tested for three times across these three sessions (chips, ice cream and pasta), other measures (BSCS, BMI, DEBQ-R and DEBQ-D) was tested once at the end of the study (pasta session).

[a] $p < 0.05$; [b] $p < 0.01$.

3.5.3 Direct effect of explicit self-control on food energy intake

Results derived from the hierarchical regression analysis are summarised in Table 3.4. For chips energy intake, regression analysis showed that there was no significant effect for hunger [β = -0.116, t = -0.89, N.S] and BMI [β = 0.158, t = 1.21, N.S] control variable on the prediction of chips energy intake at step 1 [$F_{(2, 60)}$ = 1.35, N.S], which took up a 4.4% of the total explained variance. Explicit self-control was entered at step 2. However, there was no significant effect for explicit self-control [β = -0.065, t = -0.48, N.S] on the prediction of chips energy intake above control variables, which accounted for a further 0.4% of the explained variance [$\Delta F_{(3, 57)}$ = 0.96, N.S].

For ice cream energy intake, regression analysis showed that there was no significant effect for hunger [β = -0.079, t = -0.60, N.S] and BMI [β = 0.173, t = 1.30, N.S] control variable on the prediction of ice cream energy intake at step 1 [$F_{(2, 60)}$ = 1.30, N.S], which took up a 4.3% of the total explained variance. At step 2, there was no significant effect for explicit self-control [β = 0.057, t = -0.41, N.S] on the prediction of ice cream energy intake above control variables, which accounted for a further 0.3% of the explained variance [$\Delta F_{(3, 57)}$ = 0.91, N.S].

For pasta energy intake, regression analysis showed that there was no significant effect for hunger [β = -0.088, t = -0.69, N.S] and BMI [β = 0.185, t = 1.44, N.S] control variable on the prediction of pasta energy intake at step 1 [$F_{(2, 60)}$ = 1.31, N.S], which took up a 4.3% of the total explained variance. Explicit self-control was entered at step 2. However, there was no significant effect for explicit self-control [β = -0.070, t = -0.52, N.S] on the prediction of pasta energy intake above control variables, which accounted for an additional 0.5% of the explained variance [$\Delta F_{(3, 57)}$ = 0.95, N.S].

Table 3.4 - Results from the hierarchical regression analysis using explicit self-control on different food energy intake (chips, ice cream and pasta). Significant F-statistics, standardised regression coefficients (β) and R square are highlighted in bold (p < or = 0.10).

		β(step1)			**β(step2)**		
Steps	Variables entered	Chips	Ice cream	Pasta	Chips	Ice cream	Pasta
1	Hunger	-0.12	-0.08	-0.09	-0.12	-0.09	-0.09
	BMI	0.16	0.17	0.18	0.14	0.15	0.17
2	BSCS				-0.06	-0.06	-0.07
	R^2	0.04	0.04	0.04	0.05	0.05	0.05
	ΔR^2	0.01	0.01	0.01	0.00	0.00	0.00
	ΔF	1.35	1.30	1.31	0.96	0.91	0.95

BSCS =Brief self-control scale; Body Mass Index (BMI; kg/m^2).

3.5.4 Mediation analysis: liking as a mediator

The PROCESS macro program was used to test whether liking mediated the relationship between disinhibited eating and food energy intake across different food types (Figure 3.2). The predictor (disinhibited eating) was regressed on the mediating variable (liking), showing that disinhibited eating had a significant effect on the prediction of chips liking [B = 12.18, $t_{(59)}$ = 2.85, p = 0.006], a tendency of significant effect on prediction of pasta liking [B = 6.67, $t_{(59)}$ = 1.93, N.S], but no effect on ice cream liking prediction [B = 7.33, $t_{(59)}$ = 1.52, N.S] (pathway 1, Figure 3.2). A second regression model was estimated, regressing the predictor (disinhibited eating) and mediator (liking) on the outcome variable (food energy intake). Liking was a significant predictor of energy intake for chips [B = 4.12, $t_{(59)}$ = 3.16, p = 0.003], ice cream [B = 4.23, $t_{(59)}$ = 3.55, p < 0.001] and pasta [B = 10.33, $t_{(59)}$ = 2.73, p = 0.008] (pathway 2, Figure 3.2). A third regression model was estimated, regressing the predictor (disinhibited eating) on the outcome variable (food energy intake), disinhibited eating was not successfully predict food energy intake for chips [B = 28.22, $t_{(59)}$ = 0.61, N.S], ice cream [B = 35.50, $t_{(59)}$ = 0.67, N.S] and pasta [B = 130.30, $t_{(59)}$ = 1.23, N.S] (pathway 3, Figure 3.2). The indirect effect of disinhibited eating on food energy intake through liking was 50.21 (SE = 24.60) for chips, 31.00 (SE = 31.65) for ice cream and 68.91 (SE = 59.25) for pasta, respectively. The 95% confidence interval of the estimated indirect effect did not contain zero (10.80, 106.30), indicating that the mediation was only significant for chips, but not for ice cream (-16.00, 105.50) and pasta (-8.12, 215.88).

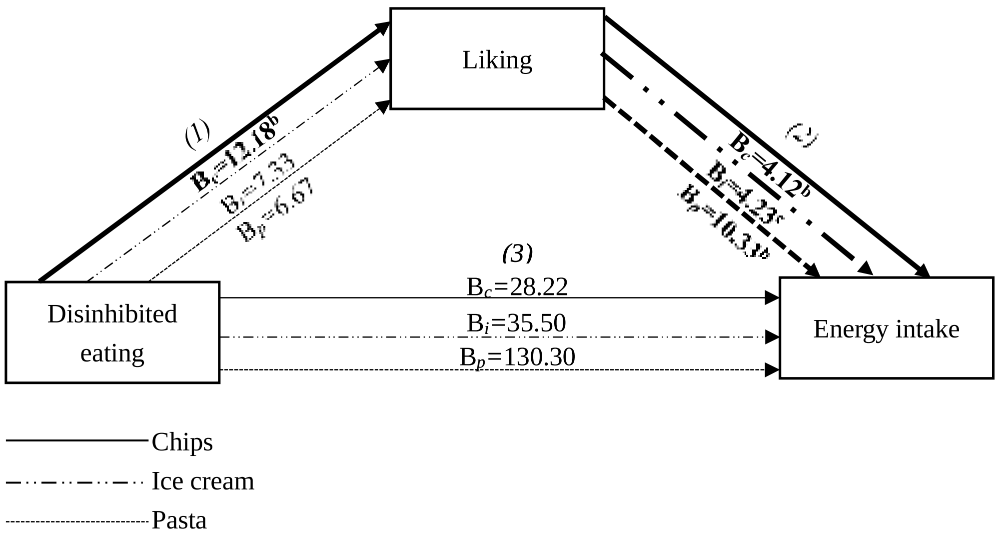

Figure 3.2 - Mediation model pathways: effect of disinhibited eating on food energy intake via liking. Bold arrows denote significant relationships.

$^a p < 0.05$; $^b p < 0.01$; $^c p < 0.001$.

3.5.5 Moderation analysis: self-control as a moderator

Moderation analysis was applied to explore whether explicit self-control moderated the relationship between disinhibited eating and food energy intake for individuals with low and high self-control. Moderation analysis (model 5) was conducted in PROCESS macro program with 5000 bootstrap samples to estimate the pathways shown in Figure 3.3 (Hayes, 2013). For chips, the predictor variables (explicit self-control and disinhibited eating), two-way interaction and mediator variables (chips liking) were regressed on the chips energy intake, showing that the overall regression model [$F_{(4, 56)}$ = 2.58, p = 0.047, R^2 = 0.16] was significant. Chips liking [B = 4.01, $t_{(56)}$ = 2.97, p =

0.004] emerged as a significant predictor. However, disinhibited eating [*B* = -32.06, $t_{(56)}$ = -0.62, N.S], explicit self-control [*B* = -16.02, $t_{(54)}$ = -0.38, N.S] and two-way interaction (between explicit self-control and disinhibited eating) [*B* = -28.51, $t_{(56)}$ = -0.34, N.S] had no significant effect on the prediction of chips energy intake. The criteria of statistical significance for the moderating effect was approved when the CI did not include zero in the moderation analysis. The associated 95% confidence intervals of the estimated direct conditional effects for low (-125.68, 94.44) and high self-control (-216.24, 119.26) contained zero (Table 3.5). This indicated that self-control did not moderate the relationship between disinhibited eating and chips energy intake, no relationship was observed in individuals with low [*B* = -15.62, $t_{(56)}$ = -0.28, N.S] and high self-control [*B* = -48.49, $t_{(56)}$ = -0.58, N.S].

For ice cream, the same model had regressed on the ice cream energy intake, showing that the overall regression model [$F_{(4, 56)}$ = 4.96, p = 0.002, R^2 = 0.26] was significant. Both ice cream liking [*B* = 4.92, $t_{(56)}$ = 4.14, $p < 0.001$] and two-way interactions (between explicit self-control and disinhibited eating) [*B* = -191.73, $t_{(56)}$ = -2.28, p = 0.026] emerged as significant predictors. However, disinhibited eating [*B* = -64.21, $t_{(56)}$ = -1.25, N.S], and explicit self-control [*B* = -38.69, $t_{(56)}$ = -0.92, N.S] had no significant effect on the prediction of ice cream energy intake. The criteria of statistical significance for the moderating effect was approved when the CI did not include zero in the moderation analysis. The associated 95% confidence intervals of the estimated conditional effects for high self-control (-347.34, -2.11) did not contain zero, but low self-control did (-54.75, 147.36) (Table 3.5). This indicated that self-control moderated the relationship between disinhibited eating and ice cream energy intake such that a negative relationship was observed in those with high self-control [*B* = -174.72, $t_{(56)}$ = -2.03, p = 0.047], but no relationship was observed in those with low self-control [*B* = 46.31, $t_{(56)}$ = 0.92, N.S]. The estimated direct conditional effects of self-control on the relationship between disinhibited eating and ice cream energy intake was -174.72 for high self-control.

For pasta, the same model had regressed on the pasta energy intake, showing that the overall regression model [$F_{(4, 56)}$ = 2.36, N.S, R^2 = 0.14] was marginally significant. Only pasta liking [B = 10.46, $t_{(56)}$ = 2.62, p = 0.011] emerged as a significant predictor. However, disinhibited eating [B = 44.09, $t_{(56)}$ = 0.37, N.S], explicit self-control [B = -73.33, $t_{(56)}$ = -0.73, N.S] and the two-way interaction (between explicit self-control and disinhibited eating) [B = 3.76, $t_{(56)}$ = 0.02, N.S] had no significant effect on the prediction of pasta energy intake. The criteria of statistical significance for the moderating effect was approved when the CI did not include zero in moderation analysis. The associated 95% confidence interval of the estimated direct conditional effects for low (-215.48, 299.33) and high self-control (-349.16, 441.68) contained zero (Table 3.5). This indicated that explicit self-control did not moderate the relationship between disinhibited eating and pasta energy intake, no relationship was observed in individuals with low [B = 41.93, $t_{(56)}$ = 0.33, N.S] and high self-control [B = 46.26, $t_{(56)}$ = 0.23, N.S].

Table 3.5 - Conditional direct effects of explicit self-control on the relationship between disinhibited eating and food energy intake at low and high self-control.

	Self-control	Conditional direct effect	
		Coefficient estimate (SE)	95% CI
	Low	-15.62 (54.94)	-125.68, 94.44
Chips	High	-48.49 (83.74)	-216.24, 119.26
	Low	46.31 (50.45)	-54.75, 147.36
Ice cream	High	**-174.72 (86.17)** [a]	**-347.34, -2.11**
	Low	41.93 (128.49)	-215.48, 299.33
Pasta	High	46.26 (197.39)	-349.16, 441.68

[a] Point estimate significantly different from zero, as 95% CI did not contain zero.

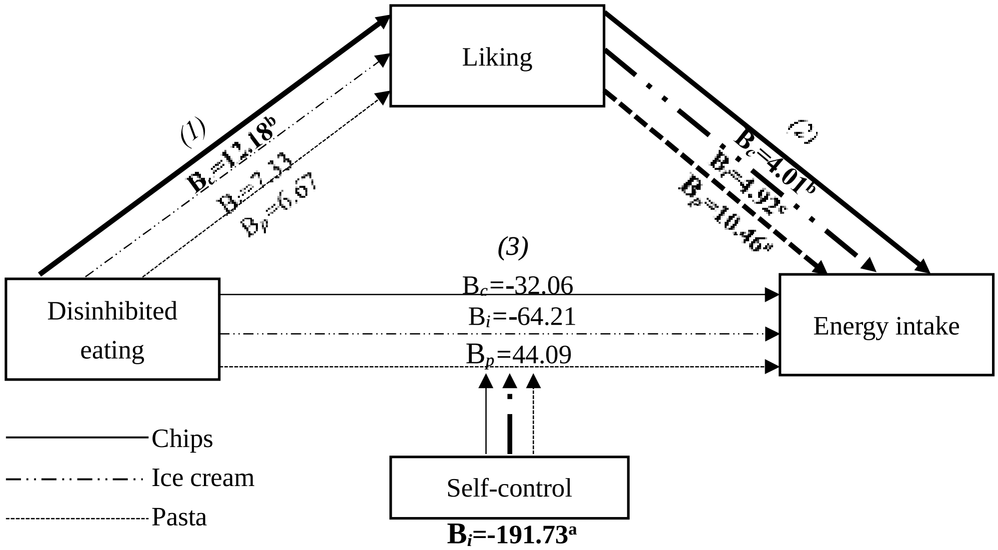

Figure 3.3 - Moderation pathways: the relationship between disinhibited eating and food energy intake by self-control. Note. Bold arrows denote significant relationships or moderation of adjoining relationships by self-control.

$^{a}p < 0.05$; $^{b}p < 0.01$; $^{c}p < 0.001$

3.5.6 Moderated mediation model analysis: self-control as a moderator

To explore whether liking mediated the relationship between disinhibited eating and food energy intake for individuals with low and high self-control, across different food types, a moderated-mediation model (model 14) was conducted in PROCESS macro program with 5000 bootstrap samples to estimate the pathways shown in Figure 3.4 (Hayes, 2013). For chips, the predictor variables (explicit self-control and disinhibited eating), two-way interaction and mediator variables (chips liking) were regressed on the chips energy intake, showing that overall regression model [$F_{(4, 56)} = 5.52$, $p < 0.001$, $R^2 = 0.28$] was significant. Both chips liking [$B = 4.70$, $t_{(56)} = 3.79$, $p < 0.001$] and the two-way interaction (between explicit self-control and disinhibited eating) [$B = -6.71$, $t_{(56)} = -3.17$, $p = 0.003$] emerged as significant predictors. However, disinhibited eating [$B = -73.18$, $t_{(56)} = -1.59$, N.S] and explicit self-control [$B = -16.79$, $t_{(56)} = -0.43$, N.S] had no significant effect on the prediction of chips energy intake. The criteria of statistical significance for the moderating effect was approved when the CI did not include zero in moderated mediation analysis. The associated 95% confidence intervals of the estimated conditional direct effects did not contain zero for low (4.82, 12.33) self-control (Table 3.6). This indicated that self-control moderated the relationship between chips liking and chips energy intake, such that a positive relationship was observed in those with low self-control [B = 8.57, $t_{(56)}$ = 4.58, p < 0.001], but no relationship was observed in those with high self-control [B = 0.83, $t_{(56)}$ = 0.52, N.S]. The estimated direct conditional effect of self-control on the relationship between chips liking and chips energy intake was 8.57 for low self-control. The associated 95% confidence interval of the estimated indirect conditional effects did not contain zero for low (35.94, 188.05) self-control. This indicated that self-control moderated the relationship between disinhibited eating and chips energy intake via liking. Such a positive relationship was observed in those with low self-control, but no relationship was observed in those with high self-control (Table 3.6). The estimated indirect conditional effects of self-control on the relationship between disinhibited eating and chips energy intake via liking was 104.46 for low self-control.

For ice cream, the same model had regressed on the ice cream energy intake, showing that overall regression model [$F_{(4, 56)}$ = 3.36, p = 0.016, R^2 = 0.19] was significant. Only ice cream liking [B = 4.35, $t_{(56)}$ = 3.45, p = 0.001] emerged as a significant predictor. However, disinhibited eating [B = -7.89, $t_{(56)}$ = -0.17, N.S], explicit self-control [B = -32.16, $t_{(56)}$ = -0.73, N.S] and two-way interaction (between explicit self-control and disinhibited eating) [B = 0.33, $t_{(56)}$ = 0.19, N.S] had no significant effect on the prediction of ice cream energy intake. Due to no significant difference for two-way interaction (between explicit self-control and disinhibited eating), this indicated that self-control did not play a moderation role in this relationship.

The same model had regressed on the pasta energy intake, showing that the overall regression model [$F_{(4, 56)}$ = 2.36, N.S, R^2 = 0.14] was marginally significant. Only pasta liking [B = 10.46, $t_{(56)}$ = 2.70, p = 0.009] emerged as a significant predictor. However, disinhibited eating [B = 44.40, $t_{(56)}$ = 0.39, N.S], explicit self-control [B = -73.32, $t_{(56)}$ = -0.74, N.S] and the two-way interaction (between explicit self-control and disinhibited eating) [B = 0.22, $t_{(56)}$ = 0.03, N.S] had no significant effect on the prediction of pasta energy intake. Due to no significant difference for the two-way interaction being found (between explicit self-control and disinhibited eating), it showed that self-control did not play a moderating role in this relationship.

Table 3.6 - Overall conditional direct and indirect effects of explicit self-control on the relationship between disinhibited eating and food energy intake via liking at low and high self-control.

	Self-control	Indirect effect (*12*)		Direct effect (*2*)	
		Coefficient estimate (SE)	95% CI	Coefficient estimate (SE)	95% CI
Chips	Low	**104.46 (39.43)** [a]	**35.94, 188.05**	**8.57 (1.87)** [a]	**4.82, 12.33**
	High	10.17 (19.55)	-20.13, 58.50	0.83 (1.60)	-2.36, 4.03

[a] Point estimate significantly different from zero, as 95% CI did not contain zero.

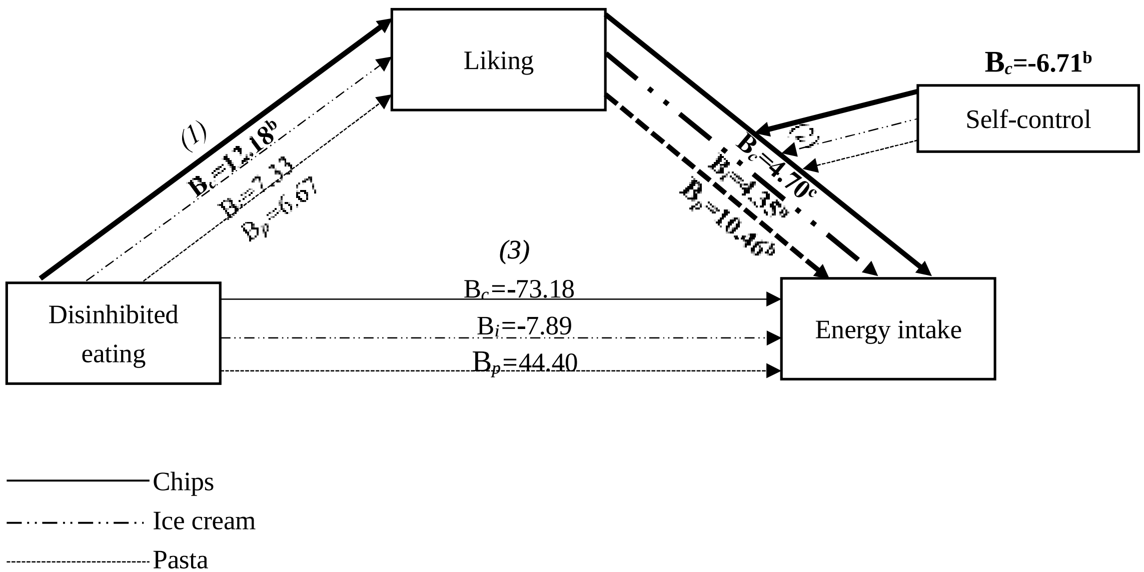

Figure 3.4 - Moderated mediation pathways: effect of disinhibited eating on food energy intake via liking. Model of the indirect effect of liking on food energy intake by self-control. Note. Bold arrows denote significant relationships or moderation of adjoining relationships by self-control.

[a] $p < 0.05$; [b] $p < 0.01$; [c] $p < 0.001$.

3.6 Discussion

The current study investigated the role of self-control in different eating scenarios. Findings from the study suggest that self-control had no direct effect on food energy intake across all food types. In addition, data from this study indicated that liking only mediated the relationship between disinhibited eating and chips energy intake. Moreover, self-control moderated the relationship between disinhibited eating and chips energy intake via liking such that a positive relationship was observed in those with low self-control. In addition, self-control moderated the relationship between disinhibited eating and ice cream energy intake such that a negative relationship was observed in individuals with high self-control, but no such moderating role of self-control was observed in the pasta eating scenario.

3.6.1 Direct effect of explicit self-control on food energy intake

The current data substantiated the fact that explicit self-control has no direct effect on food energy intake across different eating scenarios. Previous research that assessed the effect of explicit self-control on food intake has found contrasting results. Some studies observed that explicit self-control has no direct effect on potato chips intake (Friese & Hofmann, 2009), chocolate consumption (Wang et al., 2015), snack intake (Haynes et al., 2014), amount of cookies eaten (Hagger et al., 2013) and sweet pastry consumption frequency (Robinson et al., 2016). However, other studies suggested that explicit self-control was found to be significantly associated with snack energy intake (Haynes et al., 2016), healthy food consumption (Giese et al., 2015), an unhealthy snack eaten (Adriaanse et al., 2014) and sugar-sweetened soda consumption frequency (Robinson et al., 2016). Findings from the current study corroborate the former that no direct effect of explicit self-control on food energy intake was found. This is in line with the meta-analysis of self-control review that a small effect of explicit self-control on eating behaviour was found (De Ridder et al., 2012).

3.6.2 Moderating role of explicit self-control on the relationship between disinhibited eating and food energy intake

The current study was the first to investigate the moderating role of explicit self-control on the relationship between disinhibited eating and food energy intake. Specifically, findings from the current data suggest that self-control moderated the relationship between disinhibited eating and chips energy intake via liking such that a positive relationship was observed in those with low self-control. This indicates that individuals with higher disinhibited eating experienced stronger hedonic responses towards palatable food (Bryant et al., 2008; Keeler, Mattes, & Tan, 2015). Impulses for instant gratification are driven by the hedonic response when individuals are exposed to food temptations (Metcalfe & Mischel, 1999). Difficulties in inhibiting such impulses may cause self-control failure (Metcalfe & Mischel, 1999), especially for individuals with low self-control (Gillebaart & Ridder, 2015). Previous studies found the moderating role of self-control on the variety effects of food consumption, low self-control individuals had a higher desire for more food and increased food intake in the presence of multi-foods (Haws & Redden, 2013). Indulging in unhealthy food consumption keeps low self-control individuals away from their weight regulation goals (De Ridder et al., 2012; Metcalfe & Mischel, 1999).

Results from this study also suggest that self-control moderated the relationship between disinhibited eating and ice cream energy intake, such that a negative relationship was observed in individuals with high self-control. The current data added to the existing evidence that top-down control processes (Heatherton, 2011; Hofmann, Schmeichel, & Baddeley, 2012), seem to be a critical factor for regulating eating behaviour (De Ridder et al., 2012; Metcalfe & Mischel, 1999). High self-control individuals are more concerned with weight regulation goals when exposed to tempting foods (Hofmann et al., 2008), they can successfully monitor their food consumption even in the presence of multi-foods (Haws & Redden, 2013). The self-control process is more likely to activate their dieting goals unconsciously by tempting food (Fishbach et al., 2003), which has been further substantiated by the goal-conflict model (Stroebe et al., 2008). It is, therefore, easier for high self-control individuals to avoid food temptations in order to achieve their dieting goals since they experienced fewer motivational conflicts (Büttner et al., 2014; Hofmann, Baumeister, et al., 2012).

3.6.3 The top-down process in the relationship between disinhibited eating and food energy intake

Findings from the current study found the moderating role of self-control in the chips and ice cream, but not in the pasta eating scenario. Therefore, whether the top-down control process occurs may depend on the food types. Latest eye-tracking research found contrasting results between desserts and main dishes in terms of food choice and expected food intake (Wang et al., 2018), which suggests that a difference exists between these two types of food in the decision-making process. The evidence suggests that the decision-making behind food choice can vary considerably across food types (*i.e.*, desserts vs. main meals) (Graham et al., 2011; Wang et al., 2018), which engages different processes of reward, emotion and cognitive functioning (Rangel, 2013; Rolls & Grabenhorst, 2008). In the current study, participants were asked to abstain from food consumption for two hours before the chips and ice cream sessions or five hours before the pasta session. Participants perceived pasta as the lunch option to satisfy their hunger (Morton, Cummings, Baskin, Barsh, & Schwartz, 2006). Therefore, participants may treat the pasta with a less complex decision-making process compared with the other two types of food. It may explain why the moderating role of self-control was found in chips and ice cream, but not for the pasta eating scenario.

3.6.4 The relationship between disinhibited eating and food energy intake

Results from the present study suggest that disinhibited eating did not successfully predict food energy intake across different eating scenarios. Previous research assessed that disinhibited eating and food consumption has produced a mixture of findings. While some studies found that individuals with high disinhibited eating habits were more likely to have a higher intake of chocolate cookies and savoury crackers (Ouwens et al., 2003a, 2003b), other observed no association between disinhibited eating and ice cream and milkshake consumption (Ouwens et al., 2007; Van Strien et al., 2000). Findings from the current study corroborate the latter with no predictive relationship between disinhibited eating and food energy intake. The possible explanation about the inconsistencies related to disinhibited eating and food consumption in the literature may be due to the disinhibition effect not being triggered. The disinhibition effect reflects the occurrence of overeating and opportunistic eating (Bryant et al., 2008; Preedy et al., 2011), which can be triggered by the presence of high energy, palatable food and low self-control (Mills & Palandra, 2008). Numerous studies have shown disinhibition effect did not occur when individuals are exposed to high energy palatable food (Jansen, Klaver, Merckelbach, & van den Hout, 1989; Timko, Juarascio, & Chowansky, 2012). No occurrence of the disinhibition effect in previous research may contribute to the individual difference in top-down control processes. This evidence suggests that the disinhibition effect can vary considerably across food types. It may also explain why no relationship was found between disinhibited eating and food energy intake across these three different eating scenarios.

3.6.5 The bottom-up process in the relationship between disinhibited eating and food energy intake

The current data found that hedonic responses (***i.e.***, food liking) successfully predicted food energy intake across different eating scenarios. This is in line with previous studies, which found a close association between hedonic properties of food and the amounts, and the types of foods consumed (Bobroff & Kissileff, 1986; de Castro, Bellisle, & Dalix, 2000; Doets & Kremer, 2016; Guy-Grand, Lehnert, Doassans, & Bellisle, 1994; Spiegel, Shrager, & Stellar, 1989; Yeomans, 1996; Yeomans, Gray, Mitchell, & True, 1997). Hedonic experience elicited by food is a primary driver of eating (Blundell, Dalton, & Finlayson, 2013; Horner et al., 2016). Indeed, enhanced liking for a specific food leads to increased susceptibility to overeating (Finlayson & Dalton, 2012). What people eat in their daily life is mainly based on food preferences that are driven by the pleasure derived from consuming food (Blundell, Dalton, & Finlayson, 2013). Therefore, food preferences can produce a strong influence on food consumption (Horner et al., 2016).

Findings from the current study suggested that liking as a mediator showed an indirect effect on the relationship between disinhibited eating and chips energy intake. The current data added the existing evidence of a bottom-up food reward process which drives the food energy intake (Gerlach et al., 2015; van der Laan & Smeets, 2015). This indicates that individuals with higher disinhibited eating experience a high hedonic response to chips, then indulge in unhealthy chips consumption. The current findings support the review of Bryant et al. (2008) that disinhibited eating was related to liking high-fat food and making more unhealthy food choices.

The current data only found evidence of the mediating role of liking in chips, but not in ice cream or pasta. Therefore, whether bottom-up processes were present may vary from different food types. Collective evidence suggests that people not only consider internal (*i.e.* self-control), but also external factors (*i.e.* sensory attributes and palatability) when making food decisions (De Ridder et al., 2012; Herman & Mack, 1975; Wardle, 1987). The sensory aspects of the food have been found to be one of the most important factors influencing food choice and energy intake (Driskell, Meckna, & Scales, 2006; Honkanen & Frewer, 2009; Sørensen, Møller, Flint, Martens, & Raben, 2003). For instance, a previous study assessed the food choice motivations of teenagers on vending machines. Their findings suggest that teenagers were most concerned about the taste of food, followed by hunger and price (French, Story, Hannan, & Breitlow, 1999). The difference in sensory characteristics (*i.e.*, flavour, texture and taste) between different product types (chips, ice cream and pasta) may explain why a mediating role was only found for chips, but not for ice cream or pasta. Since the current study did not collect the sensory attributes of tested products, it would be useful to explore how a bottom-up process mediates sensory properties of food and its palatability on different food consumption in future studies.

3.7 Limitations

A limitation of the present study is that all three eating scenarios were only tested in laboratory-based settings. Such settings may face the challenge of getting people to act in a natural way. Previous research suggested that the food liking rating (***e.g.*** bread and salad) was significantly higher in a laboratory than in a dining hall (Meiselman, Johnson, Reeve, & Crouch, 2000). However, other research observed no difference between laboratory and dining hall in terms of food liking ratings (***e.g.*** bread and salmon) (Peryam & Haynes, 1957). According to the lasted systematic review on comparing food liking rating (9 food groups) between laboratory-based setting and field-based setting, this review suggested high correlations were only found in snack food groups between these two settings, but not in the main meal (de Graaf et al., 2005). Therefore, whether people consumed food in a natural way in the laboratory-based settings may depend on the food types. Although diverse food stimuli were tested in a laboratory including sweet snack, savoury snack and the main meal, it remains to be examined in future research whether the current findings generalise the effect of self-control on food energy intake in the "real world".

Another limitation of the present study is the information provided (***e.g.*** movie) may influence eating behaviour. The previous study suggested that the attention paid to the movie was positively associated with popcorn intake (Wansink & Park, 2001). A 20-minutes non-food related documentary was set up in the current study as a distraction. The aim of the documentary set up was to prevent bias data caused by participants counting on the food they consumed. This set up may influence energy intake due to the distraction of the documentary may cause the satiation overlooked (Poothullil, 2002). Moreover, the previous study found that movie clip had a significant influence on provoking mood (Jampour, Jafarirad, Cheraghian, & Behrouzian, 2019). Such mood induction may cause negative or positive emotion, personal emotion states may trigger their emotional eating behaviour (Macht, 2008). Faith, Allison, and Geliebter (1997) defined emotional eating as individuals who are dealing with negative emotions and coping with the negative effects of emotion. When people are in a bad mood, they will easily have excessive consumption (Heatherton, 2011) and indulge in risky eating behaviours (Baumeister & Heatherton, 1996). Davis and Claridge (1998) found that the emotional state of sadness hindered the individual's cognitive control of eating. Moreover, the previous study found that negative emotions can increase eating behaviour and food intake (Pudel & Richter, 1980). However, there are also a few studies believed that negative emotions can not only increase eating but also reduce eating (Macht, 2008). Although the definition of emotional eating is to deal with negative emotions, some researchers have also found that positive emotions can also affect the individual's eating behaviour. For example, a previous study carried out by Patel and Schlundt (2001) found that individuals can increase food intake simply by imagining more happy situations. Moreover, Macht, Roth, and Ellgring (2002) also found that positive emotions had an effect on individual's eating behaviour. Since the current study did not collect data for the documentary on mood induced (whether this documentary causes positive or negative emotion states), in future studies it would be useful to further explore how the documentary used in this study influences on eating behaviour.

3.8 Conclusion

The current study adds important insights into the top-down and bottom-up processes in food energy intake. Specifically, the results of the current study showed (1) self-control had no direct effect on food energy intake; (2) liking only mediated the relationship between disinhibited eating and chips energy intake; and (3) self-control moderated the relationship between disinhibited eating and chips energy intake via liking such that a positive relationship was observed in those with low self-control. In addition, self-control moderated the relationship between disinhibited eating and ice cream energy intake such that a negative relationship was observed in individuals with high self-control. As such, it usefully contributes to current knowledge of top-down and bottom-up processes in food energy intake across different food types.

Chapter 4: The effect of self-control on portion size and energy density of food

In preparation for submission to Appetite

Geng, X., Mirosa, M., Oey, I. & Peng, M. The effect of self-control on portion size and energy density of the food. *Appetite (in preparation)*.

4.1 Summary

In the current obesogenic environment, foods often have high energy densities (ED) and are often presented in large portion sizes (PS). The behavioural trait-food self-control (FSC)-is hypothesised to be an important factor in determining individual differences in food temptation. Previous research affirms self-control is crucial for keeping homeostatic balance. However, it remains unknown how food self-control moderates portion size and energy density. The current study examined the effects of self-control on PS and ED. Specifically, the food self-control task was employed to divide 44 female participants into high and low food self-control groups. Two high (***i.e.*** Chocolate bar and Fudge) and two low (***e.g.*** Grapes and Mandarins) calorie foods were prepared for two food choice and one consumption task. During the food choice task, participants were presented with five different food arrangements and asked to select the plate that you would like to consume as a snack. Their food intake was tested with these four foods in two ad libitum sessions (fasting versus non-fasting). Results derived from a stratified Cochran-Mantel-Haenszel test revealed that food self-control was only associated with energy density choice. In addition, data from this study showed that food self-control only influenced choices around the energy density of food, with high self-control individuals choosing foods with significantly lower food energy density. Furthermore, conditions (fasting versus non-fasting) had no effect on portion size and energy density of the food. Overall, this study systematically provides important insights into the role of self-control in regulating eating behaviour, which can potentially help with the development of intervention strategies targeting the energy density of foods.

4.2 Introduction

Previous research that assessed trait self-control and food consumption has produced a mixture of findings. While some studies observed that positive effects of high trait self-control are evident in consumption of healthy foods (***e.g.*** fruits) (Giese et al., 2015; Hankonen et al., 2013), others have found little effect of trait self-control on snack intake and alcohol consumption (Friese & Hofmann, 2009; Haynes et al., 2014). Inconsistencies of findings in the literature could be due to the construct of trait self-control as a general measure applies in different disciplines (various domains) rather than targets on the food-specific domain. Latest research suggested that food self-control (FSC) could facilitate greater insights into various eating scenarios (food domain), which was developed from trait self-control measure (Haws, Davis, & Dholakia, 2016b). This study applied both Tangney's self-control and FSC methods suggests that food self-control (FSC) could predict on snack consumption more effectively comparing to Tangney's self-control. FSC as an improved version of self-control method was applied in the current study (Haws, Davis, & Dholakia, 2016b). Emerging data have suggested that FSC, regarded as a validated self-reported measure, could be particularly useful for capturing individual differences in different eating behaviour (Haws, Davis, & Dholakia, 2016a). The positive effects of high FSC are evident in healthy eating across different food types and eating scenarios (Haws et al., 2016a; Haws et al., 2016b). Specifically, individuals with high food self-control typically select healthier snacks and had lower consumption of unhealthy food (***e.g.*** chocolate bars) (Haws et al., 2016a; Haws et al., 2016b). This evidence suggests that high self-control individuals have healthy food choice, which contributes to their successful weight management (French, Epstein, Jeffery, Blundell, & Wardle, 2012; Haws et al., 2016b).

Expectedly, energy intake and self-control frequently interact with each other. The total energy intake is determined by the portion size (PS) and energy density (ED) of food

(Kling et al., 2016). Often, high energy density food (HEDF) with large portion sizes can elicit strong eating impulses (Cahayadi, Geng, Mirosa, & Peng, 2019; Kral & Rolls, 2004); difficulties in suppressing such impulses lead to failure of self-control and countermand an individual's ability to achieve long-term goals, such as weight regulation (Metcalfe & Mischel, 1999). In particular, ineffective self-control is more likely to occur when an individual is attracted to instantaneous satisfaction due to the reward of high energy density food (HEDF) (Gillebaart & Ridder, 2015). In contrast, effective self-control is associated with a strong awareness of long-term goals, even in the presence of instantaneous satisfaction stimuli (Hofmann et al., 2008). While previous literature has confirmed the role of self-control in regulating energy intake, there is little understanding about the effect of trait food self-control on PS and ED.

The aim of the present chapter is to assess the effect of self-control on portion size and energy density. Specifically, the present chapter discusses the effect of self-control in influencing an individual's portion size and energy density in both food choice and food consumption. Findings from this study provided important insights into the role of self-control in regulating eating behaviour, which can potentially help the construction of intervention strategies for weight management.

4.3 Methods

4.3.1 Participants

The sample size calculation of the present study was based on data from pilot testing. Specifically, it was based on an effect size of 0.9 (between high and low food self-control groups) on food intake with a standard deviation of 1.0 with 80% power and an alpha level at 5%; the calculation indicates 21 participants in each condition group. Eight additional participants were recruited to account for participants' withdrawal. This study initially recruited 50 healthy females from the general community of Dunedin, New Zealand. A total of 44 (M_{age} = 23.77, SD = 4.60, Range:18-35) of them completed this study. A self-reported questionnaire was carried out to assess food self-control (FSC) (Appendix 2). During the recruiting stage, participants were classified into high and low self-control groups based on the median split of FSC scores (Haws et al., 2016b). None of them was undertaking any diet program. Ethical approval for this study was granted by the University of Otago Human Ethics Committee (Reference number:19/020).

4.3.2 Food stimuli

For stimuli preparation, two high (Mars-Snickers: 482.56 Kcal/100g; Pams-Fudge: 403.73 Kcal/100g) and two low (Australian Grown-Grape: 71.91 Kcal/100g; Halo-Mandarin: 43.96 Kcal/100g) caloric commercially available foods were selected. In total, 10 different food arrangements were prepared in a food-grade laboratory. The reason for presenting different types of food is to prevent bias data caused by personal preference on one food over another using a single food type. For the portion size (PS) choice component, the conditions of all food arrangements increased by 1 unit of each food item (Rolls, Roe, Kral, Meengs, & Wall, 2004). Overall, the weight of the plate for each food combination increased by 28.5 grams. The energy density of all five food arrangements (A1-A5) was 289.83 Kcal/100g (Table 4.1). For the energy density (ED) choice component, the conditions of all food arrangements increased by 6.5% of the total weight for each high-calorie food, reduced 6.5% of the total weight for each low-calorie food (Kral & Rolls, 2004). Overall, the weight of the plate for each food combination (B1-B5) was constant (100g) with an energy density range from 100.31 to 300.62 Kcal/100g.

Table 4.1 - Stimuli used in the present study with energy density (Kcal/100g).

Tasks	Food stimuli arrangements	Energy density
A	A1: Grape: 6.5g; Mandarin: 5g; Snickers: 9g; Fudge: 8g	289.83
	A2: Grape: 13g; Mandarin: 10g; Snickers: 18g; Fudge: 16g	289.83
	A3: Grape: 19.5g; Mandarin: 15g; Snickers: 27g; Fudge:24g	289.83
	A4: Grape: 26g; Mandarin: 20g; Snickers: 36g; Fudge:32g	289.83
	A5: Grape: 32.5g; Mandarin: 25g; Snickers: 45g; Fudge: 40g	289.83
B	B1: Grape: 44.5g; Mandarin: 44.5g; Snickers: 5.5g; Fudge: 5.5g	100.31
	B2: Grape: 38g; Mandarin: 38g; Snickers: 12g; Fudge: 12g	150.39
	B3: Grape: 31.5g; Mandarin: 31.5g; Snickers: 18.5g; Fudge: 18.5g	200.46
	B4: Grape: 25g; Mandarin: 25g; Snickers: 25g; Fudge: 25g	250.54
	B5: Grape: 18.5g; Mandarin: 18.5g; Snickers: 31.5g; Fudge: 31.5g	300.62

4.3.3 Procedure

Each participant attended two sessions (fasting vs non-fasting) with at least a two-week wash-out period. In the fasting session, participants fasted overnight for at least 10 hours prior to the session (Karim, Burns, Janky, & Hurwitz, 1985). In the non-fasting session, participants were asked to consume a standardised breakfast (porridge with milk) as much or as less as they want until they feel full (Lee et al., 2016). They then refrained from eating food for 2 hours prior to the session. The order of fasting and non-fasting condition was counterbalanced across two different self-control groups. All testing sessions were held between 8:00 and 11:00h at a standard eating-behaviour laboratory.

For both the fasting and non-fasting session, participants were asked to perform a series of tasks, as illustrated in Figure 4.1. At the start of each session, participants were instructed to indicate their hunger level on a 100-mm *Visual Analogue Scale* (*VAS*) (refer to section 2.3.3; page 41) (Flint et al., 2000). A similar VAS was also used to ask for participants' hedonic responses to each food stimulus (refer to section 3.3.3; page 66). Subsequently, participants were performed in the Food Choice Task (Task 1). Then these participants were asked to consume the food *ad libitum.*

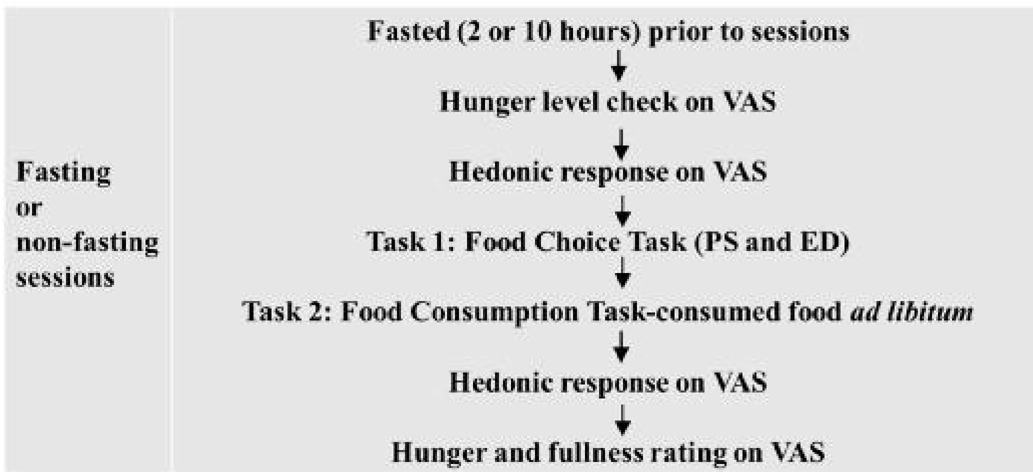

Figure 4.1 - An outline of the experimental events and the various tasks in the current study.

Task1: The Food Choice Task consists of a portion choice component (A) and an energy density choice component (B), as illustrated in Figure 4.2. Participants were presented with five different food arrangements and asked to select the plate that they would like to consume as a snack. The presentation order of both components was counterbalanced across participants.

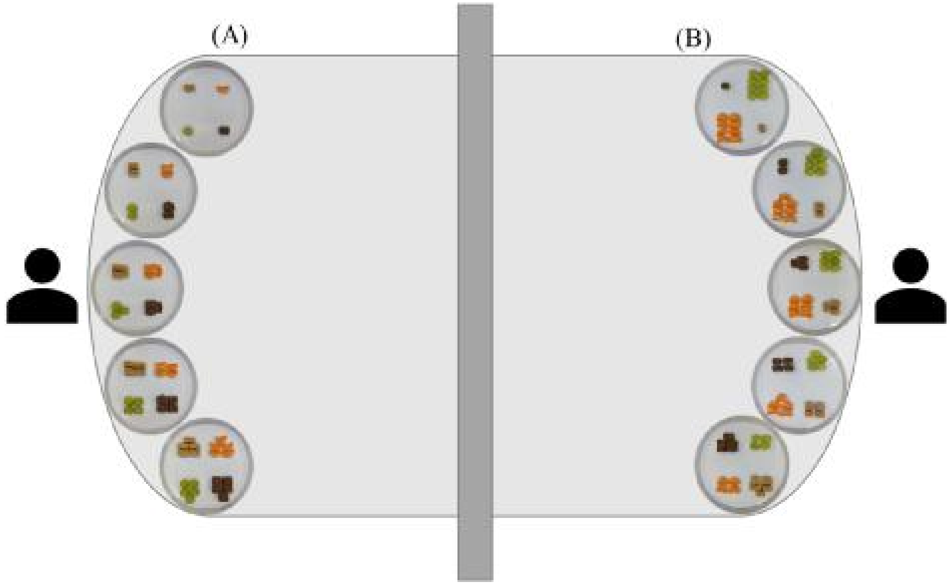

Figure 4.2 - Representations of the layout of the Food Choice Task (component A: portion choice; component B: energy density choice).

Task2: In the Food Consumption Task, the same type of foods were presented in 200g quantities (Snickers: ±0.07g; Fudge: ±0.10g; Grapes:±0.11g; Mandarins: ±0.14g) each labelled with its product name. Participants were given a plate and asked to select any type of food for a 10mins movie, they can select as much as they would like to eat. After food selection, their food choice in the plate was weighed. Participants were asked to sit in a sensory booth, equipped with a computer screen and a pair of headphones. Then all types of food were moved into the sensory booth next to participants. They were instructed to watch a 10-minutes non-food related documentary. They received the instruction as "Please pay full attention to this film, you will be asked some questions about this film after". During the film, participants were asked to consume the food ***ad libitum***, they could refill the plate until the movie ended. After 10 minutes, the leftover was also weighed for calculating food intake.

Subsequently, participants were instructed to indicate their fulness, hunger level and food hedonic responses after Task 2 (*i.e.*, answering to "how full are you feeling at this moment?" on a similar VAS). Upon the completion of these tasks, participants filled out the Dutch Eating Behaviour Questionnaire (DEBQ) (Van Strien et al., 1986b). Their height and weight were measured to calculate Body Mass Index (BMI; kg/m^2). All response data were collected by Qualtrics© (USA, 2016).

4.4 Data analyses

4.4.1 Cochran-Mantel-Haenszel (CMH) test

The first part of the analysis aimed to assess the effect of self-control in influencing an individual's food choice on portion size and energy density in different fasting conditions. Given the multilevel nature of the categorical data from Food Choice Task 1, Cochran-Mantel-Haenszel (CMH) test as an extension of chi-square test was applied to ascertain the relationship of categorical data in multiple groups (Anderson, 1996). Such a test can be applied to stratify multiple chi-square tests across multiple groups (Adejumo & Adetunji, 2013). In the current study, the first stratified CMH test was performed to ascertain the relationship between food self-control and both choices (PS and ED) by stratified conditions (fasting and non-fasting). The second stratified (CMH) test was performed to ascertain the relationship between conditions and both choices (PS and ED) by stratified food self-control groups (high and low). The CMH analysis was carried out using a JMP statistical package (SAS Institute, Cary, NC).

4.4.2 Mixed-effects linear models

The second part of the analysis aimed to test the effects of self-control on portion size and energy density in different conditions (fasting and non-fasting). Energy density for these foods was calculated using the nutrition panel calculator developed by Food Standards Australia New Zealand. Portion size is defined by the total weight of the plate (grams) and the amount of food consumed in the plate, which was calculated as the total weight of all types of food (weight) in the plate. Energy density is defined as energy content per unit weight of all types of food consumed in the plate (kcal/100g), which was calculated as the total energy of all types of food consumed divided by total weight of all types of food in the plate. Mixed-effect linear models were conducted to assess the effects of self-control on portion size and energy density. Self-control groups, conditions (fasting and non-fasting) and its interactions were included as fixed factors. ‘Participants ID’ was entered as a random factor. Subsequently, Post-hoc tests (Paired-Samples t-tests) were used to test individual differences between high and low self-control for portion size and energy density. These analyses were performed using SPSS 25 (Chicago, IL).

4.5 Results

4.5.1 Participants’ characteristics

Table 4.2 summarises the basic measures of participants’ characteristics. A series of Paired-Sample t-tests were carried out to examine the homogeneity between the high and low self-control groups, including BMI, age, DEBQ-R and DEBQ-D. The results suggested that only DEBQ-D was significantly different across the food self-control groups ($p < 0.05$), no other significant difference was present. Subsequently, a series of repeated-measures univariate analysis of variance (ANOVA) was performed to detect significant differences in different conditions, such as fasting and non-fasting; between high and low self-control groups for hunger and liking ratings for each type of food. Notably, results from repeated-measures ANOVA suggested that only grape liking was significantly different across the self-control groups, defined by the FSC, with the high self-control group having higher grape liking. No other significant difference was present.

Table 4.2 - Summary of descriptive statistics (mean and standard deviation) of the self-control and other measures obtained in the current study.

	Participants' characteristics					
	Age	BMI	DBEQ-R	DBEQ-D	Hunger-non-fasting	Hunger-fasting
Low self-control (N=22)	23.41 (4.43)	22.55 (2.73)	2.36 (0.79)	3.02 (0.50)	44.64 (26.20)	66.91 (30.31)
High self-control (N=22)	24.14 (4.85)	21.43 (2.86)	2.58 (0.77)	2.76 (0.45)	52.23 (24.55)	72.18 (22.25)
t-statistics	0.519	-1.325	0.907	-1.765	0.992	0.658
p -value	0.606	0.192	0.370	0.085	0.327	0.514

FSC =Food self-control scale; Hunger-F=hunger level of fasting condition; Hunger-NF=hunger level of non-fasting condition; BMI = Body mass index; DEBQ-R= Dutch Eating Behaviour Questionnaire-Restrained eating; DEBQ-D= Dutch Eating Behaviour Questionnaire-disinhibited eating (the mean of the scores of Dutch Eating Behaviour Questionnaire-Emotional eating and External eating).

4.5.2 The association between self-control, conditions (fasting and non-fasting) and food choice

Cochran-Mantel-Haenszel (CMH) tests were performed to assess the association between food self-control and food choices by stratified conditions (fasting and non-fasting). Results derived from the CMH test showed that self-control was only significantly associated with energy density choice (p = 0.008), but not with portion size choice (N.S).

Similar Cochran-Mantel-Haenszel (CMH) tests were applied to evaluate the association between conditions (fasting and non-fasting) and food choices by stratified food self-control. However, no significant differences were found between conditions (fasting and non-fasting) and food choices for both ED (N.S) and PS (N.S). Results derived from the CMH test are summarised in Table 4.3.

Table 4.3 - Results from stratified Cochran-Mantel-Haenszel (CMH) for portion size and energy density choice. Significant association and ***p*-**value are highlighted in bold (p < or = 0.05).

	N (%)			**PS choice (N=44)**					**ED choice (N=44)**		
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5
FA	LFSC	2(4.55)	3(6.82)	7(15.91)	7(15.91)	3(6.82)	4(9.09)	6(13.64)	6(13.64)	4(9.09)	2(4.55)
	HFSC	3(6.82)	4(9.09)	6(13.64)	5(11.36)	4(9.09)	9(20.45)	7(15.91)	2(4.55)	2(4.55)	2(4.55)
N-FA	LFSC	2(4.55)	5(11.36)	3(6.82)	9(20.45)	3(6.82)	5(11.36)	4(9.09)	7(15.91)	5(11.36)	1(2.27)
	HFSC	5(11.36)	7(15.91)	5(11.36)	2(4.55)	3(6.82)	8(18.18)	9(20.45)	4(9.09)	1(2.27)	0(0)
CMH				p = 0.133					***p* = 0.008**		
LFSC	FA	2(4.55)	3(6.82)	7(15.91)	7(15.91)	3(6.82)	4(9.09)	6(13.64)	6(13.64)	4(9.09)	2(4.55)
	N-FA	2(4.55)	5(11.36)	3(6.82)	9(20.45)	3(6.82)	5(11.36)	4(9.09)	7(15.91)	5(11.36)	1(2.27)
HFSC	FA	3(6.82)	4(9.09)	6(13.64)	5(11.36)	4(9.09)	9(20.45)	7(15.91)	2(4.55)	2(4.55)	2(4.55)
	N-FA	5(11.36)	7(15.91)	5(11.36)	2(4.55)	3(6.82)	8(18.18)	9(20.45)	4(9.09)	1(2.27)	0(0)
CMH				p = 0.312					p = 0.582		

PS= Portion size; ED= Energy density; FA = Fasting; N-FA=Non-fasting; LFSC =Low food self-control; HFSC =High food self-control; CMH= Cochran-Mantel-Haenszel test.

4.5.3 Differences in portion size between self-control groups in different conditions (fasting and non-fasting)

Figure 4.3 displays the averaged measure of portion size (PS) across different self-control groups. Mixed-effects linear models were employed to assess the differences for PS of food between self-control groups in different conditions (fasting and non-fasting).

The analysis based on PS indicated no significant difference between high and low self-control for PS [$F_{(1,42)}$ = 0.004; N.S]. Furthermore, no significant difference was found for PS [$F_{(1,42)}$ = 0.019; N.S] between fasting and non-fating conditions. In addition, there were no significant interactions between self-control and conditions for PS [$F_{(1,42)}$ = 0.742; N.S].

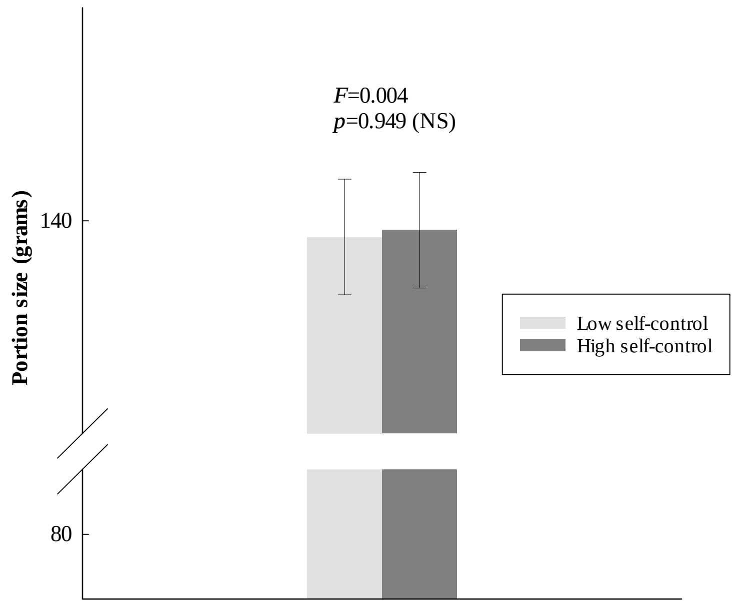

Figure 4.3 - Displays the averaged measure of portion size (PS) (grams) across different self-control groups. The mixed linear model was employed to assess differences across the groups estimated by food self-control measures.

4.5.4 Differences in energy density between self-control groups in different conditions (fasting and non-fasting)

Figure 4.4 displays the averaged measure of energy density (ED) across different self-control groups. Mixed-effects linear models were employed to assess the differences for ED between self-control groups in different conditions (fasting and non-fasting).

Notably, the analysis based on ED indicated significant differences between high and low self-control for ED [$F_{(1,42)} = 4.174$; $p = 0.047$]. A post-hoc test (t-test) conducted on ED suggested that the high self-control group reported significantly lower ED (M = 161.67, SE = 14.5) compared to the low self-control group (M = 203.83, SE = 14.59) (Figure 4.4). However, no significant difference was presented between fasting and non-fating conditions for ED [$F_{(1,42)}$ = 0.533; N.S]. Moreover, there were no significant interactions between self-control and conditions for ED [$F_{(1,42)}$ = 0.032; N.S].

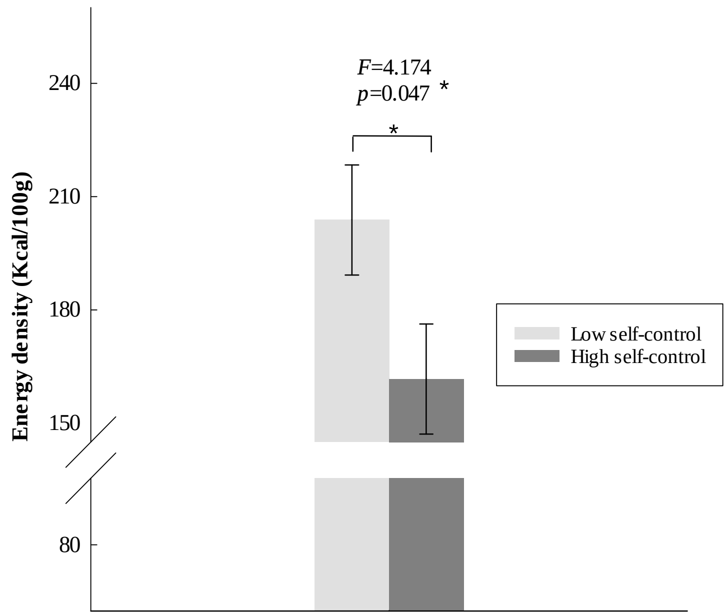

Figure 4.4 - Displays the averaged measure of energy density (ED) (Kcal/100g) across different self-control groups. The mixed linear model was employed to assess differences across the groups estimated by food self-control measures.

4.6 Discussion

The present study aimed to assess the effects of self-control on portion size (PS) and energy density (ED) in the context of the multi-food presentation. Specifically, the study examined whether differences existed between self-control groups for PS and ED in different conditions (fasting and non-fasting). Findings from the study suggested that a significant difference between high and low self-control was found only for energy density, but not for the portion size. In addition, data from this study revealed conditions (fasting and non-fasting) had no effect on both ED and PS.

4.6.1 Differences in energy density between high and low self-control groups

The current study is the first to investigate how food self-control influences on the energy density of food intake. In general, findings from the study suggested high self-control individuals had significantly lower energy density intake compared to low self-control individuals, adding to the existing evidence for the top-down impulse control process of high self-control individuals on food choice decision (Gerlach et al., 2015; van der Laan & Smeets, 2015). This finding is consistent with previous studies whereby individuals with high food self-control often choose low-energy, healthy snacks and consumed less of high energy density food (HEDF) (*e.g.* chocolate bar) (Haws et al., 2016a; Haws et al., 2016b). This evidence confirms that high self-control individuals are more resistant to impulses elicited by temptation-related stimuli such as high ED palatable food (Fishbach & Shah, 2006). Fujita (2011) proposed the dual-motive conflicts model of self-control that represents a conflict between two types of motivators: to obtain a smaller, instant reward (pleasure associated with consuming palatable food) or to pursue a bigger, long-term reward (weight management). Effective self-control is associated with a strong awareness of long-term goals, even in the presence of instantaneous satisfaction (Hofmann et al., 2008). The process of successful self-control consists of proactively adopting strategies to avoid the possibility of conflict, rather than adopting conscious conflict-inhibiting behaviour after the conflict has emerged. The current finding supported Fujita's view that high food self-control individuals had proactively avoided foods with a high energy density. The tendency to decrease intake of high ED foods contributed to successful weight management for high food self-control individuals (Haws et al., 2016a; Haws et al., 2016b).

The current study found that only low self-control individuals had significantly higher energy density intake compared to high self-control individuals, which adds to the existing evidence for the bottom-up food reward drives processes of low self-control individuals on food choice decision (Horner et al., 2016). This finding is consistent with previous studies that whereby individuals of low self-control are evident in unhealthy eating behaviour and weight gain (Gillebaart & Ridder, 2015; Junger & van Kampen, 2010; Salmon, Fennis, de Ridder, Adriaanse, & De Vet, 2014). Collectively, this evidence confirmed that low self-control individuals are more difficult to resist the temptation of delicious foods due to lacking self-control (Houben et al., 2012; Tangney et al., 2004). Often, responses to palatable food can elicit strong eating impulses; difficulties in suppressing such impulses lead to failure of self-control and countermand an individual’s ability to achieve long-term goals, such as weight regulation (Metcalfe & Mischel, 1999). In particular, unsuccessful self-control is more likely to occur when an individual is attracted to instantaneous satisfaction due to reward of palatable food, especially in the presence of multi-foods (Gillebaart & Ridder, 2015; Haws & Redden, 2013). Latest research suggested that lacking self-control increased susceptibility to the variety effect of food, low self-control individuals had a higher desire for more food and increased food intake in the presence of multi-foods (Haws & Redden, 2013).

4.6.2 Differences in portion size between high and low self-control groups

The current study is the first to investigate how food self-control influence on food portion size. Findings from the study suggested that self-control has no effect on PS. One of the possible explanations may be the influences of internal (***i.e.*** triggering self-control) and external factors (***i.e.*** multi-food cues, self-serving portion size). The self-serving processes in the current multi-food presentation involved conscious thought on the meal planning— how big of a PS they wish to consume to satisfy their hunger level (Pourshahidi et al., 2014). Possibly, participants have different habitual portions for each type of food (Kral, 2006). During a self-serving process, it may be more difficult for participants to correctly identify the perceived portion size for each type of food in a multi-food condition compared with a single food one (Kral, 2006). Previous studies which assessed the portion size effects for multi-food items found that no difference was found in perceived portion size for different multi-foods, between different eating scenarios. Participants fail to differentiate the portion size and their habitual portion, even doubled portion sizes were presented to them (Kral, Meengs, Wall, Roe, & Rolls, 2003). Therefore, self-serving portion sizes may not offer an ‘Everyone fits the mould’ approach to promoting the avoidance of food over-consumption (Pourshahidi et al., 2014).

Previous studies suggested that self-serving portion size had no influence on decreasing people’s entrées energy intake (Savage, Haisfield, Fisher, Marini, & Birch, 2012). Even though participants in certain conditions are able to properly discriminate between portion sizes of food, the majority of them are still not aware that larger food portions increase their energy intake (Kral, 2006). Previous intervention studies on activating self-control by downsizing food portions in three field tests showed that participants who accepted smaller portions did not reduce calories in their entrée ordering (Schwartz, Riis, Elbel, & Ariely, 2012). This evidence further suggests that cognitive perceptions of differences in food portions at the self-serving stage may not adjust energy intake in following food consumption. According to the dual-motive conflicts model, when individuals make food choice decision in front of both high (***e.g.*** sweet) and low energy density of food (***e.g.*** fruits). Such food context involved a conflict between two types of motivators: to obtain a smaller, instantaneous satisfaction (pleasure associated with consuming high energy density food) or to pursue a bigger, long-term goal (consuming low energy density food for successful weight management) (Fujita, 2011). Participants may perceive the multi-food cues (high vs low energy density of food) in the current study as a self-control conflict between these two motivators (Fujita, 2011). Successful triggering self-control conflict between two motivators is key in the subsequent action (Fishbach & Shah, 2006). If current states do not cause a self-control conflict, they will not trigger the coping strategies that could restrict the tempting food intake (Fishbach & Shah, 2006). Participants from the assumed tendency believe that having smaller quantities of tempting food is “acceptable” (Coelho do Vale et al., 2008). This is supported by a series of experiments regarding a restrained eater had a higher calories intake in a small packaged format (Scott et al., 2008). The latest research found that food PS cues only activated brain regions in charge of cognitive control (English, Fearnbach, Wilson, et al., 2016). In this Chapter, self-control as a trait was measured by food self-control scale, it did not involve any cognitive self-control paradigm. Future research needs to further validate the relationship between cognitive self-control and food portion size in multi-food contexts.

4.6.3 Differences in energy density and portion size between fasting and non-fasting condition

Furthermore, results from the present study suggested that no difference exists between fasting and non-fasting conditions in portion size and energy density of the food. Previous research that assessed fasting conditions and food consumption has produced a mixture of findings. While some studies observed that individuals in a fasting condition have shown to purchase higher amounts of food in response to internal cues (hunger) (Mela et al., 1996; Nisbett & Kanouse, 1969), these findings suggest that the value of food reward has been enhanced in a fasting condition (Drobes et al., 2001; Epstein, Truesdale, Wojcik, Paluch, & Raynor, 2003). In previous studies, fasting increased food reward activity in brain areas when exposed to high-calorie foods (Siep et al., 2009). An alternative study confirmed that hunger promotes impulsive processes (Seibt, Häfner, & Deutsch, 2007), which has been shown to increase Expected Intake (Brogden & Almiron-Roig, 2010). However, other studies found contrasting results. For instance, a previous food deprivation study on eating disorders found that there was no increase in food consumption, for those people without eating disorders (control group), after 19 hours fasting (Hetherington et al., 2000). The latest research on 24 hours fasting failed to cause the increase in food consumption for the next four days ad libitum sessions (Levitsky & DeRosimo, 2010). This evidence is in line with literature, which has found that skipping meals did not cause adequate compensation for the decrease in food intake (Levitsky, 2005). Findings from the current study corroborate the latter with no differences existing between fasting and non-fasting conditions in portion size and energy density of the food. This suggests that people are not able to accurately compensate for energy loss caused by fasting through having more energy intake later, even when faced with repetitive food deprivation (Heilbronn, Smith, Martin, Anton, & Ravussin, 2005; Levitsky & DeRosimo, 2010).

Baumeister, Vohs, et al. (2007) proposed the strength model of self-control, which suggests that the performance of self-control operates on the basis of a limited resource, similar to energy or strength, that can become depleted through use. Emerging evidence on the strength model of self-control investigated in a variety of eating behaviours has shown a mixture of findings (Hagger et al., 2009). Also, it has been targeted on state view and investigated how the short-term depletion effect attenuated the performance of following tasks that demand self-control ability (Hagger et al., 2013). The current finding supported the view that the trait of food self-control is an individual's relatively stable personality tendency (Tangney et al., 2004). It does not change with physiological conditions such as fasting states.

4.7 Conclusion

The current study adds important insights into the role of self-control on energy intake in both PS and ED. Specifically, the results of the current study showed: (1) significant difference between high and low self-control only in food energy density; and (2) no difference exists between fasting and non-fasting conditions in portion size and energy density of the food. As such, it usefully contributes to current knowledge of self-control in regulating eating behaviour via the energy density of the food. It indicated the possible direction of intervention strategy in future studies for those low self-control individuals.

Chapter 5: The effectiveness of cognitive training on decreasing portion size and energy density of food

5.1 Summary

Previous research suggested that modified IAT as an effective training method can successfully decrease unhealthy snack intake. However, previous studies did not consider the attentional bias (AB) aspect in top-down impulsive control processes. Hence more research is clearly needed to unravel the mechanism of modified IAT on food attentional bias and subsequent portion size (PS) and energy density (ED) in real eating scenarios. The current study assessed whether the targeted IAT can exert an effect on AB, PS and ED of food. Specifically, low self-control female participants were recruited and separated into control (N=16) and training (N=16) groups. Two high (*e.g.* French fries and Macaroni cheese) and two low (*e.g.* Garden salad and Steamed broccoli) energy density food were prepared for food consumption task. Participants did a dot-probe task to measure their attentional bias towards visual stimuli. Their food intake was tested with these four foods in two ad libitum sessions (baseline and training). Results derived from mixed-effects linear models revealed the significant interaction between training groups and sessions, which suggest that training was effective to affect both portion size and energy density, but not on attentional bias. Thus, this cognitive training was effective to affect eating behaviour. Findings from this study could add to current knowledge about modifying implicit evaluation on the behaviour changes.

5.2 Introduction

Previous research has suggested that people vary greatly in their abilities to resist rewarding foods (Soetens, Braet, Van Vlierberghe, & Roets, 2008), one of the hypotheses is related to self-control (Johnson et al., 2012). Effective self-control consists of proactively adopting strategies to avoid the possibility of conflicts for the long-term goal, rather than adopting conscious conflict-inhibiting behaviour after the conflict has emerged (Fujita, 2011). Ineffective self-control is more likely to occur when an individual is attracted to instantaneous satisfaction due to reward of palatable food, especially in the presence of multi-foods (Gillebaart & Ridder, 2015; Haws & Redden, 2013). Emerging evidence suggests that individuals with low self-control have difficulty inhibiting impulses for instantaneous satisfaction in tempting circumstances (Hofmann, Baumeister, et al., 2012; Metcalfe & Mischel, 1999), which contributes to their unsuccessful weight management (Keller, Hartmann, & Siegrist, 2016; Keller & Siegrist, 2014; Will Crescioni et al., 2011).

The information processing of body image involves body dissatisfaction, which refers to the gap between the individual's perception of their current body and the ideal body (Bulik et al., 2001), resulting in a negative evaluation of their body’s appearance; experiencing negative affect and corresponding behavioural regulation towards body weight (Cash & Deagle III, 1997; Cash & Pruzinsky, 2004). As aforementioned in section 1.8.1, body dissatisfaction has become a global problem (Tiggemann, 2011). Emerging evidence suggests that the proportion of those wishing to change body shape reached 60% for girls and 30% for boys (Ricciardelli & McCabe, 2001).

Recently, extensive research has been conducted to identify the intervention methods that help individuals with changing behaviour (Blume et al., 2010; Hardeman et al., 2002; Webb et al., 2010). In eating behaviour domain, previous research mentioned training approaches (stop signal and go/ no-go task) found positive results on intervening eating behaviour (Adams, Lawrence, Verbruggen, & Chambers, 2017;

Lawrence et al., 2015). Both methods train participants to work on their inhibitory control. Other cognitive training methods is to modify implicit evaluations based on the dual system model (Stice et al., 2016; Strack & Deutsch, 2004; van Beurden et al., 2016). Psychological studies have suggested that Evaluative Conditioning (EC) and the Implicit Association Test (IAT), two similar processes, can be employed for modifying implicit evaluations (De Houwer et al., 2001; Ebert et al., 2009). In this thesis, self-control refers to the capability to inhibit impulses in order to achieve long-term goals. The IAT training method used in this thesis is to consistently pair certain concepts and build new associations between the energy density of food and body figure (high energy density of food lead to fat figure, the low energy density of food associate with lean figure). Such IAT training methods are more suitable to remind participants with the long-term goal (weight management) and low energy density food lead to a lean figure. Therefore, IAT was chosen over other training approaches.

Previous research which assessed the effectiveness of modifying implicit evaluation, via EC or IAT, on behaviour change has produced a mixture of findings. While some studies support the successful modification of implicit evaluation in altering subsequent alcohol drinking behaviour (Houben, Havermans, et al., 2010; Houben, Schoenmakers, et al., 2010), healthy food choices (Hollands et al., 2011; Walsh & Kiviniemi, 2014) or decreased unhealthy snack intake (Haynes et al., 2015). Other studies have shown no effects of modifying implicit evaluation on behaviour (Ebert et al., 2009; Lebens et al., 2011). Inconsistencies in the literature could be related to the lack of considering the targeted population and top-down impulsive control processes. From a targeted population perspective, according to the dual-motive conflicts model (Fujita, 2011), individuals with high self-control experience less motivational conflicts and are better at avoiding temptation (Hofmann, Baumeister, et al., 2012). In spite of a modification in implicit evaluations being fulfilled among high self-control individuals, a subsequent change in eating behaviour is not likely to have occurred (Haynes et al., 2015). From a top-down process perspective, whether a modification in implicit evaluation can successfully trigger impulsive control determines the subsequent change in eating behaviour. Previous studies have found that the EC effect could be successfully obtained by pairing food images with body figures (Lascelles, Field, & Davey, 2003). Participants in the EC training can effectively increase healthy food choices by modifying their implicit evaluation (Hollands et al., 2011). In the current study, it was hypothesized that the targeted IAT on pairing food images with body figures would affect attentional bias, portion size and energy density by activating their long term-goal (successful weight management) for low self-control individuals.

Emerging data have suggested that top-down impulsive control is a critical process which plays an important role in controlling attention towards temptations (Higgs, Rutters, Thomas, Naish, & Humphreys, 2012; Peake, Hebl, & Mischel, 2002; Rodriguez, Mischel, & Shoda, 1989), particularly in the initial phases of the self-control process (Baumeister, Schmeichel, & Vohs, 2007; Metcalfe & Mischel, 1999). Increasing numbers of alcohol studies focus on training subjects to shift their attention away from harmful cues and towards harmless ones (Fadardi & Cox, 2009; Friese, Hofmann, & Wiers, 2011; Schoenmakers, Wiers, Jones, Bruce, & Jansen, 2007). The effectiveness of training can exert an effect on changing attentional bias that significantly decreased the subsequent beer consumption (Field & Eastwood, 2005). The latest research suggests that implicit association of alcohol had a close relationship with an attentional bias towards alcohol, while attention control over alcohol was associated with executive control (Friese, Bargas-Avila, Hofmann, & Wiers, 2010).

Although the implicit evaluation training on subsequent behaviour has been investigated in different disciplines (Devine et al., 2012; Girod et al., 2016), its effectiveness in real eating scenarios has not been widely investigated. Haynes et al. (2015) detailed the only study which employed modified IAT as an effective training method. This study showed that the IAT training method could successfully decrease unhealthy snack intake by modifying participants' implicit evaluation towards unhealthy snack foods, but only for low inhibitory self-control individuals. However, this study did not consider the attentional bias aspect in the top-down processes (Section 1.3.6, top-down processes also involve attentional control). Hence more research is clearly needed to unravel the mechanism of modified IAT on food attentional bias and subsequent effects on portion size and energy density in real eating scenarios. The current study was conducted to assess whether the targeted IAT can exert an effect on food attentional bias, portion size and energy density of food for low food self-control individuals. Findings from this study could add to the knowledge about understanding the mechanism on inter-individual changes in eating behaviour, which could be helpful for constructing intervention strategies, potentially helping low self-control individuals to achieve better appetite control and weight regulation.

5.3 Methods

5.3.1 Participants

Based on the pilot test, the sample size was estimated by an effect size of 0.85 (comparing the difference between baseline and training session on Food IAT training group) with a standard deviation of 1.0. Assuming 80% power at an alpha level of 5%, the power calculation suggested 23 participants in each condition group. Due to the limited time and funding, this study recruited 16 participants for each group.

A self-reported questionnaire was used to calculate the score of food-specific self-control during the recruiting stage (Haws et al., 2016b; Tangney et al., 2004). Individuals whose self-control rating score was below 4 were considered to be part of the low self-control group and was eligible to participate in this study. In total, 32 (M_{age} = 22.59, SD = 4.61) healthy female adults with low food self-control from the general community of Dunedin were chosen for this study. They were randomly assigned to one control group (N = 16) and one intervention group (N = 16). None of them was in a diet program to gain or lose weight. All participants received 20 NZD monetary compensation. Ethical approval for this study was granted by the Human Ethics Committee of the University of Otago (Reference number: 19/062).

5.3.2 Stimuli

The visual food stimuli were photographed from the real foods prepared in a food-grade laboratory. Visual food cues were categorised into high (HEDF) (243.41 to 336.39 Kcal/100g) and low energy density food (LEDF) groups (30.80 to 97.47 Kcal/100g) (Appendix 4). All visual stimuli were placed in the middle of the plate (20 X 20 cm) for photo-shooting. The visual stimuli were photographed using Nikon SX50 HS fitted with image stabilizer lens in a standardised photobooth (Raiser, RS 2 XA, Germany). The photo booth was set up with a standardised grey background installed with two white fluorescent lamps (RB 5004 HF, TC-L 36W, Germany) and a camera holder. The camera was constantly fixed at the same position as the camera holder and set up with 80 ISO, 1/125 shutter speed and F3.4 aperture for all image-shooting. All images were standardised to 500 × 500 pixels using image software (Adobe Photoshop 2017, Adobe Systems Incorporated, CA, USA).

5.3.3 Cognitive training task

In the intervention training task, participants were instructed to take part in General Food IAT training, they learnt to associate low energy density food (LEDF) with thin figures and high energy density food (HEDF) with fat figures (Moussally, Rochat, Posada, & Van der Linden, 2017). In control training task, participants were instructed to conduct a colour and shape IAT training, participants were asked to associate round shapes with green colour and triangle shapes with red colour (Miyake, Emerson, Padilla, & Ahn, 2004). During the task, the paired categories were displayed in the left-hand and right-hand corners of the screen. In each trial, the participant was asked to respond to the displayed images as fast as possible by pressing the left or right key corresponding to the correct category (Greenwald et al., 1998). The training task was carried out using psychology software INQUISIT online version (Millisecond Software

LLC, Seattle, WA, V5.0.14.0).

The whole IAT training for both tasks consisted of seven blocks (Figure 5.1). In Practice Block A1 (or B1) (160 trails), participants press the left response key when the target was fat female (or round shape) and press the right response key when the target was a thin female image (or triangle shape). In Practice Block A2 (or B2) (160 trails), participants press the left response key when the attribute food image on the screen was a low-calorie food (***e.g.*** “Garden salad”) or colour (green colour) and press the right response key when the attribute food image was a high-calorie food (***e.g.*** “French fries”) or colour (red colour). In Practice Block A3 (or B3) (the first combination Block-160 trails), participants were asked to press the left response key when the target was a low-calorie food (green colour) or was a thin female image (round shape), and press the right response key when the target was a high-calorie food (red colour) or fat female image (triangle shape). In Test Block A4 (B4), it was a combination Block same as Block A3 (B3), but the trails were 320. Block A5 (B5), A6 (B6) and A7 (B7) were the reverse block A1 (B1), A3 (B3) and A4 (B4) respectively (switched presentation of stimuli). Stimuli from all categories were presented in a random order (Greenwald et al., 1998).

(A) Intervention training: General Food IAT

(B) Control training: Colour and shape IAT

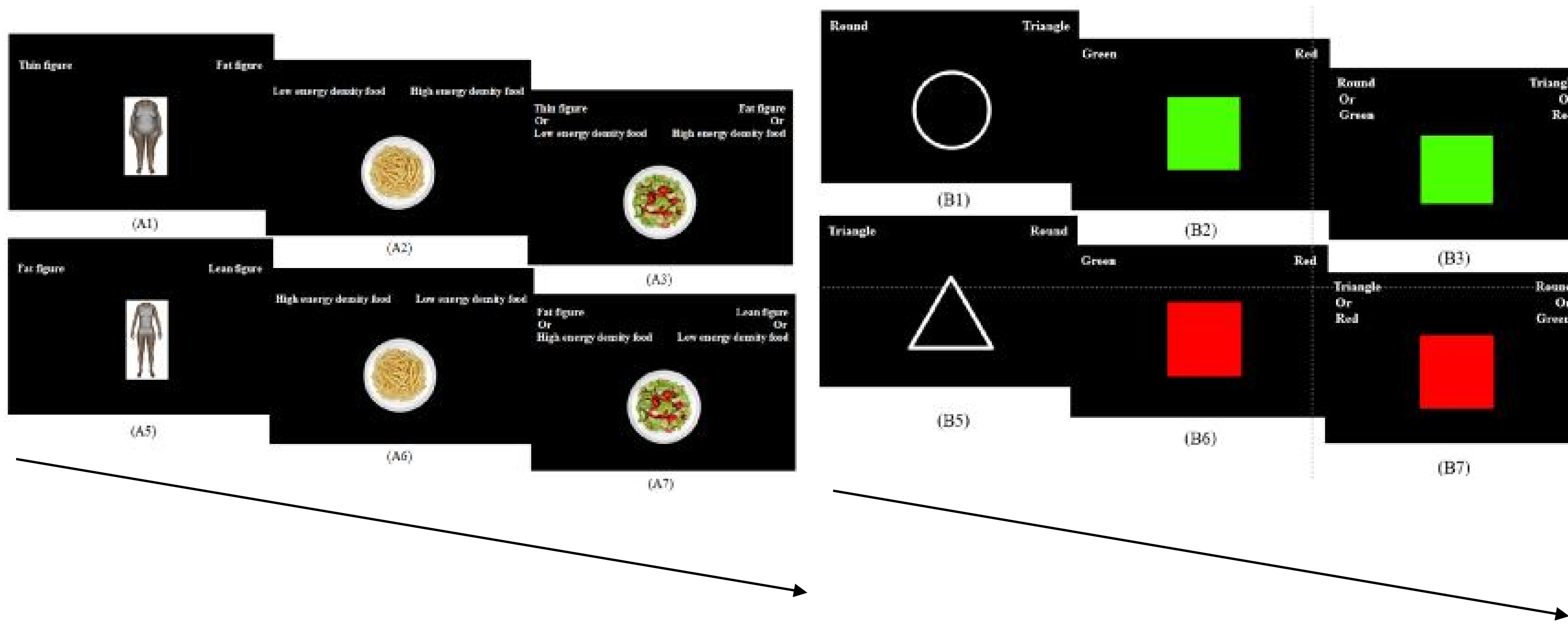

Figure 5.1 - (A) The left six squares represent a modified implicit association task (IAT)-General food IAT for intervention training. (B) The right six squares represent control training task-Control training: Colour and shape IAT.

5.3.4 Procedure

Each participant attended one baseline session first, then took part in a training session with at least one day apart. Participants were asked to abstain from food or non-water beverage for 4 hours prior to both sessions. All testing sessions were held between 11:00 and 13:00h at a standard eating behaviour laboratory.

In the baseline session, participants were asked to conduct a serious of tasks, as illustrated in Figure 5.2. At the start of each session, participants were instructed to indicate their hunger level on a 100-mm *Visual Analogue Scale* (*VAS*) (refer to section 2.3.3; page 41). Then participants did a Dot Probe Task (Task 1) to measure their attentional bias towards visual stimuli. A similar VAS was also used to ask for participants' first bite hedonic responses to each food stimulus (refer to section 3.3.3; page 66). Subsequently, participants were asked to consume the food ***ad libitum*** in Food Consumption Tasks (Task 2).

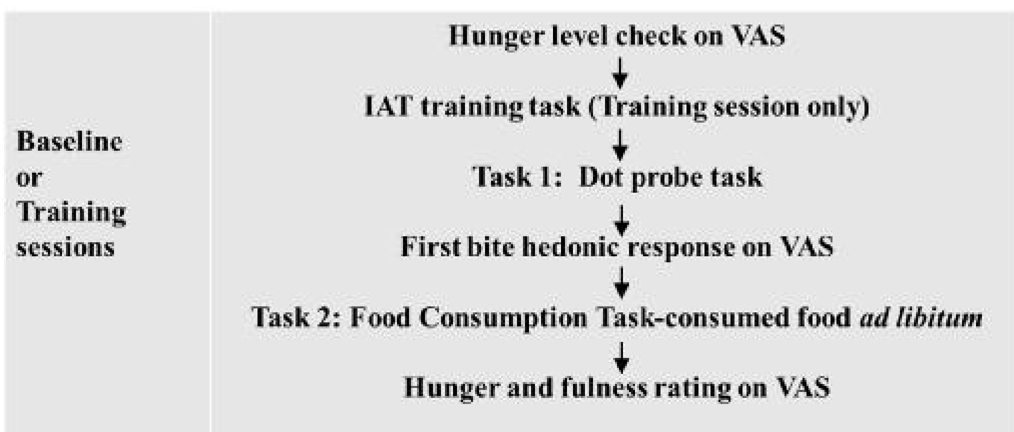

Figure 5.2 - An outline of the experimental events and the various tasks in the current study.

Task1: The same visual food cues from the cognitive training task were used in the Dot Probe Task. A matching set of pictorial stimuli were chosen from neutral household-related items (*e.g.* tong) or neutral office-related items (*e.g.* maker pen). The Dot Probe Task consisted of one practice block (10 trials) and one test block (32 trials) (Figure 5.3)

After the presentation of a fixation cross (500ms) in the centre of the screen, participants were presented with two pictures from two categories (food and neutral pictures) for 1000ms. The position of the pictures was randomly chosen to be either left or right to the location of the fixation cross. After 1000ms, the two pictures disappear and a probe stimulus (X) appeared in the location of one of the pictures with a maximum of 1000ms. Participants were asked to press the “E” key if the probe was on the left or “I” key if the probe was on the right as quickly as possible. The inter-trial interval was 500ms (MacLeod, Mathews, & Tata, 1986; Meule & Platte, 2016). Reaction time (ms) for each trial was recorded using installed psychology software INQUISIT.

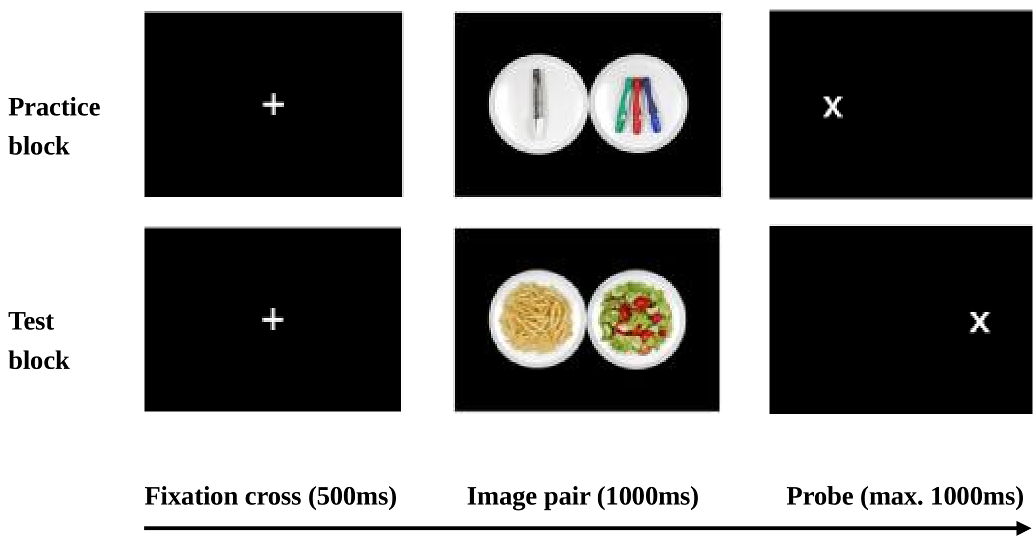

Figure 5.3 - An outline of the Dot Probe Task. Representative screen displays of the two blocks (practice and test block) of Dot Probe Task.

Task2: In the Food Consumption Task, participants were presented with two high (French fries: 650±0.07g; Macaroni cheese: 1300±0.02g) and two low (Garden salad: 1100.03±0.08g; Steamed broccoli: 850.02±0.07g) calorie foods, each labelled with a product name. Participants were given a plate and asked to select any type of food for a 40mins movie, they can select as much as they would like to eat. After food selection, their food choice in the plate was weighed. Participants were asked to sit in a sensory booth, equipped with a computer screen and a pair of headphones. They were instructed to watch a 40-minutes non-food related documentary. They received the instruction as "Please pay full attention to this film, you will be asked some questions about this film after". During the film, participants were asked to consume the food *ad libitum*, they could refill the plate until the movie ended. When participants finished eating, the leftover was weighed for calculating food intake. Their fullness and hunger level were measured after Task 2 (***i.e.*** answering "how full are you feeling at this moment?" on a similar VAS).

The training session repeated the same tasks in the baseline sessions with additional cognitive training tasks (Figure 5.4). Participants were randomly assigned into two different cognitive training tasks (intervention training or control training task), all of which involved completing a modified Implicit Association Test (IAT; Anthony G. Greenwald, McGhee, & Schwartz, 1998).

Upon the completion of these tasks in the training session, participants filled out a Dutch Eating Behaviour Questionnaire (DEBQ) (Van Strien et al., 1986b). Then participants were instructed to perform a body weight control motive task, where they were asked to rate their level of agreement with each of the 4 statements on a 7-point Likert scale (***e.g.***, I choose certain food items to keep my weight; 1 = never; 7 = always; Cronbach's a = 0.79). Their height and weight were measured to calculate Body Mass Index (BMI; kg/m^2). All response data were collected by Qualtrics© (USA, 2016).

5.4 Data analyses

5.4.1 Pearson's correlation analysis

Pearson's correlations were conducted to examine the relationship between food attentional bias, portion size, energy density, food self-control, body weight control motive, DEBQ-R and DEBQ-D. This analysis was performed across different sessions (baseline and training sessions) together with the mean scores and standard deviations of these variables.

5.4.2 Mixed-effects linear models

This study aimed to test the effect of cognitive training on food attentional bias, portion size and energy density. The actual reaction times for baseline session are the mean of congruent trials 381.77 ms with SD 56.15, the mean of incongruent 376.64 ms with SD 58.38. The actual reaction times for training session are the mean of congruent trials 383.65ms with SD 62.48., the mean of incongruent 374.73 ms with SD 64.02. The attentional bias (AB) was calculated by the mean difference between congruent and incongruent trials. The negative value of attentional bias (AB) denotes bias away from the high energy density of the food.

Energy density for these foods was calculated using the nutrition panel calculator developed by the Food Standards Australia-New Zealand. Portion size is defined as the total weight of the plate (grams) consumed, which was calculated as the total weight of all types of food (weight) on the plate. Energy density is the energy content per unit weight of the plate (Kcal/100g consumed, which was calculated as the total energy of the plate divided by the total weight of the plate.

Mixed-effects linear models were conducted to assess the effects of cognitive training on attentional bias towards high and low energy density foods. Similar models were also conducted on portion size and energy density. Training groups (intervention training and control training), sessions (baseline and training session) and its interactions were included as fixed factors. ‘Participants ID’ was entered as a random factor. Subsequently, Post-hoc t-tests (Bonferroni-adjusted p-value) were used for multiple comparisons to test interaction differences between sessions and training groups. These analyses were performed using SPSS 25 (Chicago, IL).

5.5 Results

5.5.1 Participants' characteristics

Table 5.1 summarises the basic measures of participants' characteristics. A series of Paired-Samples t-tests were carried out to examine the homogeneity between the control and training groups, including FSC, body weight control motive, hunger level in baseline and training sessions, BMI and age. The results suggested that no significant differences were present.

Subsequently, a series of repeated-measures univariate analysis of variance (ANOVA) was performed to assess liking rating differences for each type of food. Results from the repeated-measures ANOVA suggested that there was no significant difference for liking ratings between different training groups (p >0.05; Steamed broccoli; Garden salad; Macaroni cheese; French fries).

Table 5.1 - Summary of descriptive statistics (mean and standard error) of the different training groups and other measures obtained in the current study.

N=32	**Participants' characteristics**					
	FSC	BWCM	Hunger-B	Hunger-T	BMI	Age
Control (N=16)	3.13 (0.11)	3.31 (0.29)	65.31 (5.27)	78.19 (5.03)	22.00 (0.59)	22.69 (1.17)
General Food IAT (N=16)	2.94 (0.11)	3.33 (0.29)	75.63 (5.27)	81.44 (5.03)	22.19 (0.59)	22.50 (1.17)
P-value	0.250	0.970	0.177	0.651	0.824	0.911

FSC = Food self-control scale; BWCM = Body weight control motive; Hunger-B = hunger level in baseline session; Hunger-T = hunger level in training session; BMI = Body mass index.

5.5.2 Relations between study variables

Pearson's correlation coefficients between all variables in baseline and training sessions are displayed in Table 5.2. For the baseline session, correlation analyses showed that food attentional bias (AB) positively correlated to food self-control (FSC) ($r = 0.461$, $p = 0.008$). In addition, FSC was negatively associated with energy density ($r = -0.432$, $p = 0.014$). Furthermore, body weight control motive (BWCM) was negatively correlated to energy density ($r = -0.519$, $p = 0.002$). No other significant differences were present in the baseline session.

In terms of the training session, food self-control (FSC) was positively related to energy density ($r = -0.424$, $p = 0.016$). Furthermore, body weight control motive (BWCM) was negatively related to energy density ($r = -0.472$, $p = 0.006$). Moreover, portion size was negatively associated with energy density ($r = -0.460$, $p = 0.008$). No other significant differences were present in the training session.

Table 5.2 - Pearson's correlation coefficients between attentional bias, portion size, energy density, food self-control, body weight control motive, DEBQ-R and DEBQ-D in the baseline and training sessions.

Baseline session							
	AB	PS	ED	FSC	BWCM	Mean	SD
AB	—					-5.13	24.82
PS	0.20	—				468.42	161.89
ED	-0.28	-0.06	—			189.93	47.56
FSC	**0.46[b]**	0.06	**-0.43[a]**	—		3.04	0.45
BWCM	0.26	0.10	**-0.52[a]**	0.23	—	3.32	1.15

Training session							
	AB	PS	ED	FSC	BWCM	Mean	SD
AB	—					-8.93	30.14
PS	0.13	—				488.95	167.49
ED	-0.6	**-0.46[b]**	—			194.39	48.55
FSC	0.23	0.12	**-0.42[a]**	—		3.04	0.45
BWCM	-0.01	0.09	**-0.47[b]**	0.23	—	3.32	1.15

AB = Attentional bias; PS = Portion size; ED = Energy density; FSC = Food self-control scale; BWCM = Body weight control motive. [a] $p < 0.05$; [b] $p < 0.01$; [c] $p < 0.001$.

5.5.3 Interaction effect between training groups and sessions in attentional bias towards high and low energy density food

Figure 5.4 displays the average measure of attentional bias (AB) towards high and low energy density foods, estimated by sessions across different training groups. Mixed-effects linear models were employed to assess the difference for AB in terms of interaction effects between training groups and sessions. Results of these analyses are presented in Table 5.3.

Mixed-effects linear models were also applied to assess attentional bias (AB) towards high and low energy density foods in terms of interaction effects between training groups and sessions. The analysis based on AB indicated no significant interactions between training groups and sessions [$F_{(1,30)} = 0.157$; N.S]. Moreover, no significant difference was found between control and General Food Training groups [$F_{(1,30)} = 1.557$; N.S]. In addition, there were no significant differences between baseline and training sessions for AB [$F_{(1,30)} = 0.312$; N.S].

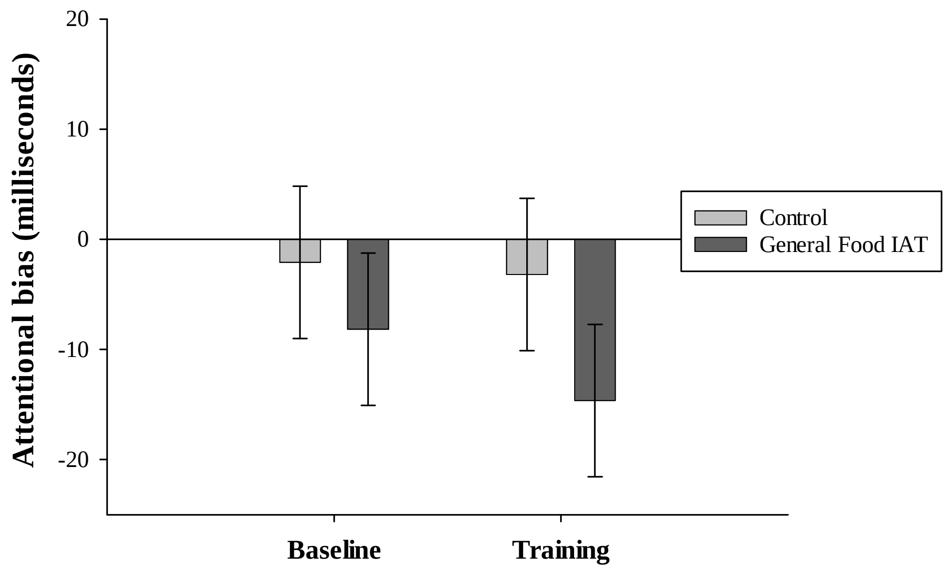

Figure 5.4 - Displays the averaged measure of food attentional bias estimated by different sessions (session 1: baseline; session 2: training) across different training groups (training group1: control group; training group 2: General Food IAT group). Notes: a negative value of attentional bias (AB) denotes bias away from the high energy density of the food.

5.5.4 Interaction effect between training groups and sessions in portion size

Figure 5.5 displays the averaged measure of portion size (PS) of each session across different training groups. Similar mixed-effect linear models were employed to assess the difference for PS in terms of interaction effects between training groups and sessions. Results of these analyses are presented in Table 5.3.

Notably, the analysis based on portion size (PS) indicated significant differences in terms of an interaction effect between training groups and sessions [$F_{(1,30)} = 9.753$; $p = 0.004$]. The significant interaction between training groups and sessions suggests that training was effective to affect portion size. A post-hoc test was conducted on PS suggested that the baseline session (M = 408.56, SE = 24.46) of the control group reported significantly lower PS compared to the baseline session of the General Food Training group (M = 483.09, SE = 24.46) [$F_{(1,30)} = 9.288$; $p = 0.005$]. The post-hoc test also suggested that the training session of the control group (M = 528.28, SE = 53.92) had a significantly higher portion size compared to the baseline sessions of the control group (M = 408.56, SE = 53.92) [$F_{(1,30)} = 4.929$; $p = 0.034$]. However, no significant difference was found between control and General Food Training groups regarding PS [$F_{(1,30)} = 1.457$; N.S]. In addition, there were no significant differences between baseline and training session for PS [$F_{(1,30)} = 1.409$; N.S].

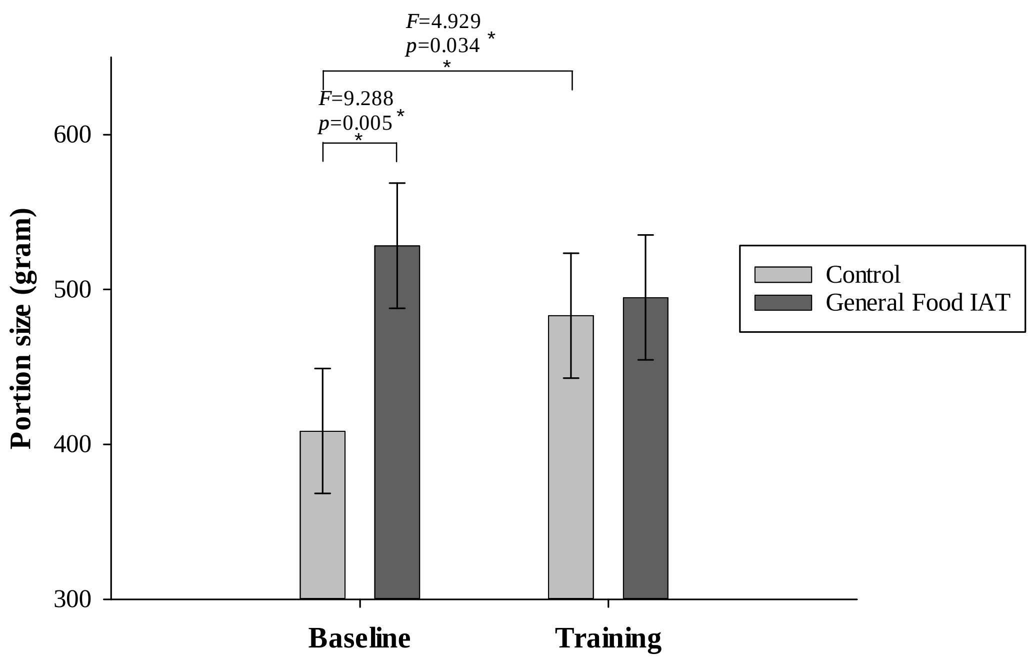

Figure 5.5 - Displays the averaged measure of portion size estimated by different sessions (session 1: baseline; session 2: training) across different training groups (training group1: control group; training group 2: General Food IAT group).

5.5.5 Interaction effect between training groups and sessions in energy density

Figure 5.6 displays the averaged measure of energy density (ED) estimated by sessions across different training groups. Similar mixed-effects linear models were employed to assess the difference for ED in terms of interaction effects between training groups and sessions. Results of these analyses are presented in Table 5.3.

Notably, the analysis indicated a significant interaction between training groups and sessions for ED [$F_{(1,30)} = 5.072$; $p = 0.032$]. The significant interaction between training groups and sessions suggests that training was effective to affect energy density. Similarly, a post-hoc test conducted on ED revealed that the baseline session of the control group (M = 182.58, SE = 6.79) had a significantly lower ED compared to the baseline session of the General Food Training group (M = 197.86, SE = 6.79) [$F_{(1,30)} = 5.061$; $p = 0.032$]. However, no significant difference in ED was found between control and General Food Training groups [$F_{(1,30)} = 0.056$; N.S]. In addition, there were no significant differences between baseline and training session for ED [$F_{(1,30)} = 5.072$; $p = 0.032$].

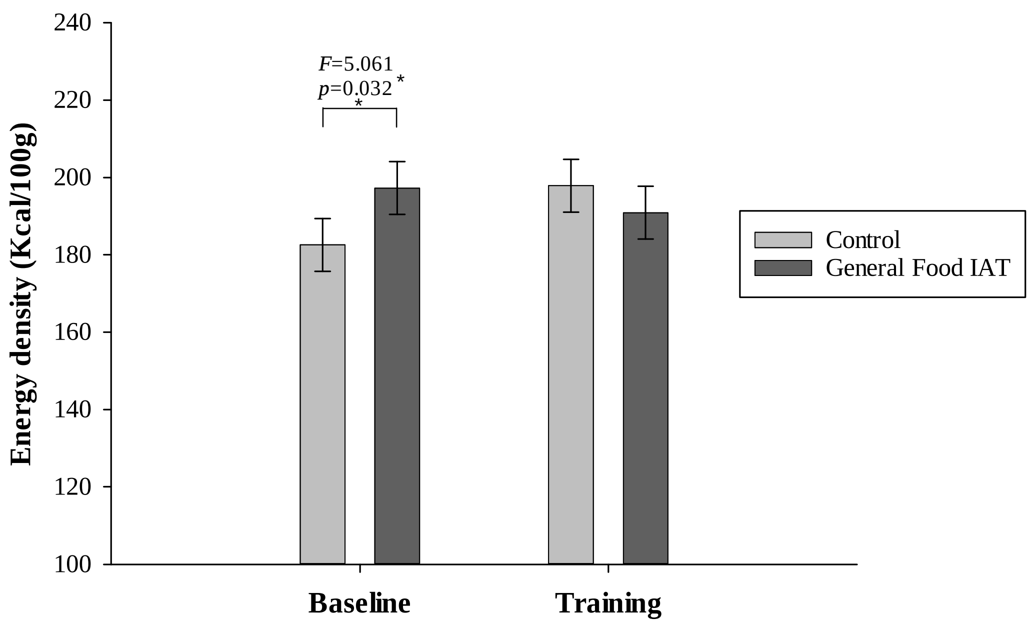

Figure 5.6 - Displays the averaged measure of energy density estimated by different sessions (session 1: baseline; session 2: training) across different training groups (training group1: control group; training group 2: General Food IAT group).

Table 5.3 - Results derived from the mixed linear models of food attentional bias, portion size and energy density. Significant F-statistics and p-values are highlighted in bold (*p* < or = 0.05).

	AB		PS		ED	
	$F_{(1, 30)}$	*P*	$F_{(1, 30)}$	*p*	$F_{(1, 30)}$	*p*
Groups	1.557	0.222	1.457	0.236	0.056	0.815
Sessions	0.312	0.580	1.409	0.245	0.863	0.360
Groups X Sessions	0.157	0.695	**9.753**	**0.004**	**5.072**	**0.032**

AB = Attentional bias; PS = Portion size; ED=Energy density; Sessions =session 1: baseline; session 2: training; Training groups = training group1: control group; training group 2: General Food IAT group.

5.6 Discussion

The present study assessed the effectiveness of cognitive training on the attentional bias (AB), portion size (PS) and energy density (ED). Specifically, the current study employed a modified IAT to examine whether the IAT training can exert an acute effect on AB, PS and ED for low food self-control individuals. Results from the study suggest that the control group showed a significant increase in their portion size between baseline and training session (and a nonsignificant increase in their attentional bias and energy density), while the training group showed a non-significant decrease on the attentional bias, energy density and portion size. The significant interaction between training groups and sessions suggests that training was effective to affect both portion size and energy density, but not on attentional bias. Thus, findings suggest that training was effective to affect eating behaviour.

5.6.1 The IAT training in affecting portion size and energy density

Findings from the current study suggest that the control training significantly increased the portion size of food on training session compared to the baseline session. During the control IAT training task, participants learned to associate the colour green with a round shape and the colour red with a triangle shape (Miyake et al., 2004). Due to no existence of such associations in their memory, it may have increased cognitive load in the training process. That may potentially contribute to the higher portion size of food on training session compared to the baseline session. This is consistent with findings from a previous study whereby individuals with a higher cognitive load find it more difficult to inhibit impulses compared to the lower cognitive load condition (Friese, Hofmann, & Wanke, 2008; Hofmann, Rauch, & Gawronski, 2007).

The significant interaction between training groups and sessions suggests that training was effective to affect both portion size and energy density. A possible explanation for such findings maybe because the automatic associative learning mechanism in General Food IAT training successfully activate participants' long term-goals (successful weight management). When participants went through General Food IAT training, this learning process is to consistently pair female body images with food images, build new associations between the high energy density of food and fat figure, and associate low energy density of food with a lean figure. Such training may remind their long-term goal. Thus, low self-control individuals from General Food training group did not act the same way as the control group –significantly increase the portion size of food in subsequent food consumption. Thus, findings suggest that IAT training affects eating behaviour.

5.6.2 The effectiveness of IAT training in reducing portion size and energy density of food

The current study is the first to investigate the effect of modified IAT training on portion size (PS) and energy density (ED) using a mixed design in the context of real buffet eating scenarios. In general, findings from the study suggest that the training of General Food IAT had no acute effect on significantly reducing the portion size and energy density in training sessions compared to baseline sessions. While the present finding is in line with the majority of the previous research (Ebert et al., 2009; Lebens et al., 2011), a few studies found contrasting results. For instance, a previous EC study on pairing food images (*e.g.* unhealthy snacks or healthy fruits) with female body images (*e.g.* fat or figure pictures) suggested that participants assessed those unhealthy foods (*e.g.* snacks) more negatively in the implicit association task. The subsequent food choice task showed that participants selected more healthy food (*e.g.* fruits) over unhealthy food (*e.g.* snacks) by successfully modifying implicit evaluation on individual behaviour changes (Hollands et al., 2011). The inconsistencies in modifying implicit evaluation on the following behaviour changes may be related to two distinguishable processes, involving a dual-systems model of information processing- the reflective (*i.e.* deliberate) and impulsive (*i.e.* automatic) systems (Fazio, 1990; Strack & Deutsch, 2004). The cognitive information process of the deliberate system prompts individuals to choose and consume low energy density healthy foods, whereas the process of automatic system induces individuals to adhere to their impulses and eat unhealthy, high energy density food (HEDF) (Hofmann et al., 2009; Lebens et al., 2011; Strack & Deutsch, 2004). The General Food IAT used in current study reflects the automatic associative learning process in memory by pairing female body images (*e.g.,* fat or figure pictures) with food images (*e.g.,* unhealthy snacks or healthy fruits) (Gawronski & Bodenhausen, 2006). However, subsequent eating behaviour (energy density and portion size of food intake) may be more involved in the deliberate process such as pre-meal planning and decision-making of food choices (De Ridder et al., 2012; Herman & Mack, 1975; Wardle, 1987). Therefore, the following food consumption is quite different from simply pairing body images with food images in the IAT training task (Lebens et al., 2011). The IAT training procedure in the current study may be more effective in modifying automatic rather than deliberate processes (Gawronski &

Bodenhausen, 2006; Lebens et al., 2011).

Previous studies suggest that even if IAT training procedures can successfully modify an automatic process, but implementation intentions are the crucial factor to fulfil goal-oriented dieting behaviour (Kroese et al., 2011; van Koningsbruggen, Stroebe, Papies, & Aarts, 2011). Previous reviews point out implementation intentions as a well-researched approach to facilitate healthy behaviour, by decreasing the effect of the impulse evoked from high energy density food (HEDF) (Adriaanse, Vinkers, De Ridder, Hox, & De Wit, 2011; Gollwitzer, 1999; Hofmann et al., 2008). This evidence suggests that individuals with high implementation intentions are more likely to fulfil dieting goals, such as by decreasing intake of fixed portions and decreasing portion size (Kroese et al., 2011; Van Kleef, Shimizu, & Wansink, 2012; van Koningsbruggen et al., 2011; Veling & Aarts, 2011). Since the current study did not collect data for implementation intention, in future studies it would be useful to further explore how long-term IAT training could modify implementation intentions for decreasing portion size and energy density of the food.

5.6.3 The effectiveness of IAT training in modulating the attentional bias

Findings from the current study suggest that food self-control is positively related to attentional bias towards food cues, adding to the existing evidence of top-down attentional control on healthy food cues (Naets, Vervoort, Verbeken, & Braet, 2018; Nervous, Diseases, Posner, & Rothbart, 1998; Stice, Yokum, Veling, Kemps, & Lawrence, 2017). This indicates that individuals with increasing food self-control have more attentional bias way from high energy density food (HEDF). The current finding is in line with the latest studies which show that attentional modulation of top-down control process can direct attention to food cues (Higgs et al., 2015; Higgs et al., 2012; Redden & Haws, 2012). Attentional control is important for high self-control individuals during the meal planning stage as they self-regulate their visual attention to healthy foods, hence avoiding the temptation from high energy density food (HEDF), behaving in line with long-term weight control goals (Berridge, Ho, Richard, & DiFeliceantonio, 2010). Previous studies suggest that high food self-control individuals typically select more healthy snacks and had lower consumption of unhealthy food (*e.g.* chocolate bar) (Haws et al., 2016a; Haws et al., 2016b). This evidence suggests that high self-control participants proactively employed strategies to avoid things which conflict with their long-term goal (Fujita, 2011). Therefore, attentional control processes are likely to be automatically triggered for these successful self-controllers because they have had previous experiences in being able to resist temptations (Fishbach et al., 2003; Nervous et al., 1998).

Further, results from the present study suggested the training of General Food IAT had no acute effect on modulating attentional bias away from high energy density food in training session compared to the baseline session. Previous studies suggest that top-down attentional control has been identified as a facilitator of existing goals embodied in working memory (Kane, Bleckley, Conway, & Engle, 2001), which is able to implement the selection processing of sensory information related to the goal (Knudsen, 2007). Therefore, weight management goals direct attention away from harmful cues and towards harmless ones. Individuals who have weight control goal in mind, sensory information of high energy density food (HEDF) did not require further processing. They ought to direct their attention to goal-related food cues (Kean & Lambert, 2003). In contrast, individuals ought to process palatable food cues more intensely in the absence of a weight management goal (Hofmann & Van Dillen, 2012; Van Dillen, Papies, & Hofmann, 2013). Findings from the current study suggest that IAT training did not modulate attentional bias away from high energy density food. The ineffectiveness of IAT training is mainly attributed to insufficient repeated exposures and the length of training time (Baddeley, 1997). In future studies, it would be useful to further explore how many trials are needed to successfully activate long-term goals effectively and modulate the attentional bias towards food cues for low self-control individuals.

5.7 Limitations

There are a few limitations in the present study. First of all, the power calculation suggested 25 participants in each condition group. Due to the limited time and funding, this study recruited 16 participants for each group. The limited sample size may restrict the generalisability of the current conclusions such as no acute effect on significantly reducing the portion size, energy density of food and modulating attentional bias in training sessions compared to baseline sessions. Future research should replicate the current findings with a large sample size. The second limitation of the present study is the inconsistency between training and control groups in terms of portion size and energy density of food in the baseline session. Larger sample size would have made it less likely. Future research should replicate the current findings with the same baseline between training and control groups.

5.8 Conclusion

The current study adds important insights into how cognitive training influence eating behaviour. Specifically, results derived from this study indicate the significant interaction between training groups and sessions, which suggest that training was effective to affect both portion size and energy density, but not on attentional bias. Thus, findings suggest that training was effective to affect eating behaviour for individuals with low food self-control. As such, it usefully contributes to current knowledge of cognitive training on influencing eating behaviour. Future research could apply a targeted measure in assessing long-term effect, in order to attain a better understanding of individual suitability for an intervention to decrease unhealthy eating.

Chapter 6: General discussions and conclusions

6.1 Overview

The overall aim of this thesis is to systematically assess the role of self-control in determining an individual's eating behaviour. Specifically, the thesis discusses the role of self-control in influencing an individual's food choice, energy intake and its determinants (***i.e.***, portion size and energy density) in different eating scenarios. Besides, this thesis examines the effectiveness of a cognitive training paradigm on moderating an individual's self-control for food choices.

Chapter 2 of this thesis tested for differences across available measures of self-control for predicting an individual's food choices for high-calorie and low-calorie sweet food. Specifically, three methods – inhibitory control test, explicit and implicit self-control task – were employed to analyse against the participant's food choices to various sweet snacks. Results derived from this study revealed that both explicit (***i.e.***, Tangney's Brief Self-Control Scale) and implicit (***i.e.***, Single Target Implicit Association Test) self-control measures can predict food choices, however, inhibitory control test failed to predict such behaviour. In addition, self-control was found to moderate the relationship between disinhibited eating and food choice. Specifically, a positive relationship was observed in those with high self-control individuals, but no relationship was observed in those with low self-control.

Chapter 3 assessed the role of self-control in determining energy intake across diverse food categories (***i.e.***, savoury snack, sweet snack and main meal). Participants, identified as having either high or low self-control according to Tangney's Brief Self-Control Scale, were tested for their eating behaviour for the abovementioned three categories of food. Results from this study showed that explicit self-control measure had no direct effect on energy intake across all scenarios (Figure 6.1). Nevertheless, the results revealed that self-control can moderate the energy intake of savoury and sweet snacks. Specifically, self-control moderated the relationship between disinhibited eating and savoury snack energy intake via liking, a positive relationship was observed in those with low self-control. In addition, self-control was also found to be able to moderate the relationship between disinhibited eating and sweet snack energy intake, where a negative relationship was observed in individuals with high self-control. However, for main meals, self-control was shown unable to moderate energy intake.

Chapter 4 tested the effect of food self-control on the two primary determinants of energy intake – *i.e.*, portion size and energy density. Participants, with either high or low food self-control (*i.e.* Food Self-Control Scale), were tested with two high and low-calorie sweet snacks in both food choice and consumption tasks. Results revealed that the effect of self-control was only present for choice based on energy density, but not for the portion size. In general, individuals with high food self-control selected lower energy density, compared to low self-control counterpart.

Chapter 5 developed a cognitive training paradigm for self-control and tested its effectiveness on influencing both portion size and energy density for individuals with low food self-control (*i.e.* Food Self-Control Scale). The training paradigm was developed based on a modified implicit association test in conjunction with body shape images. Results showed the training paradigm was able to affect eating behaviours, although individuals who underwent the training programme had no significant reduction in their portion size nor energy density intake (*i.e.* main meal).

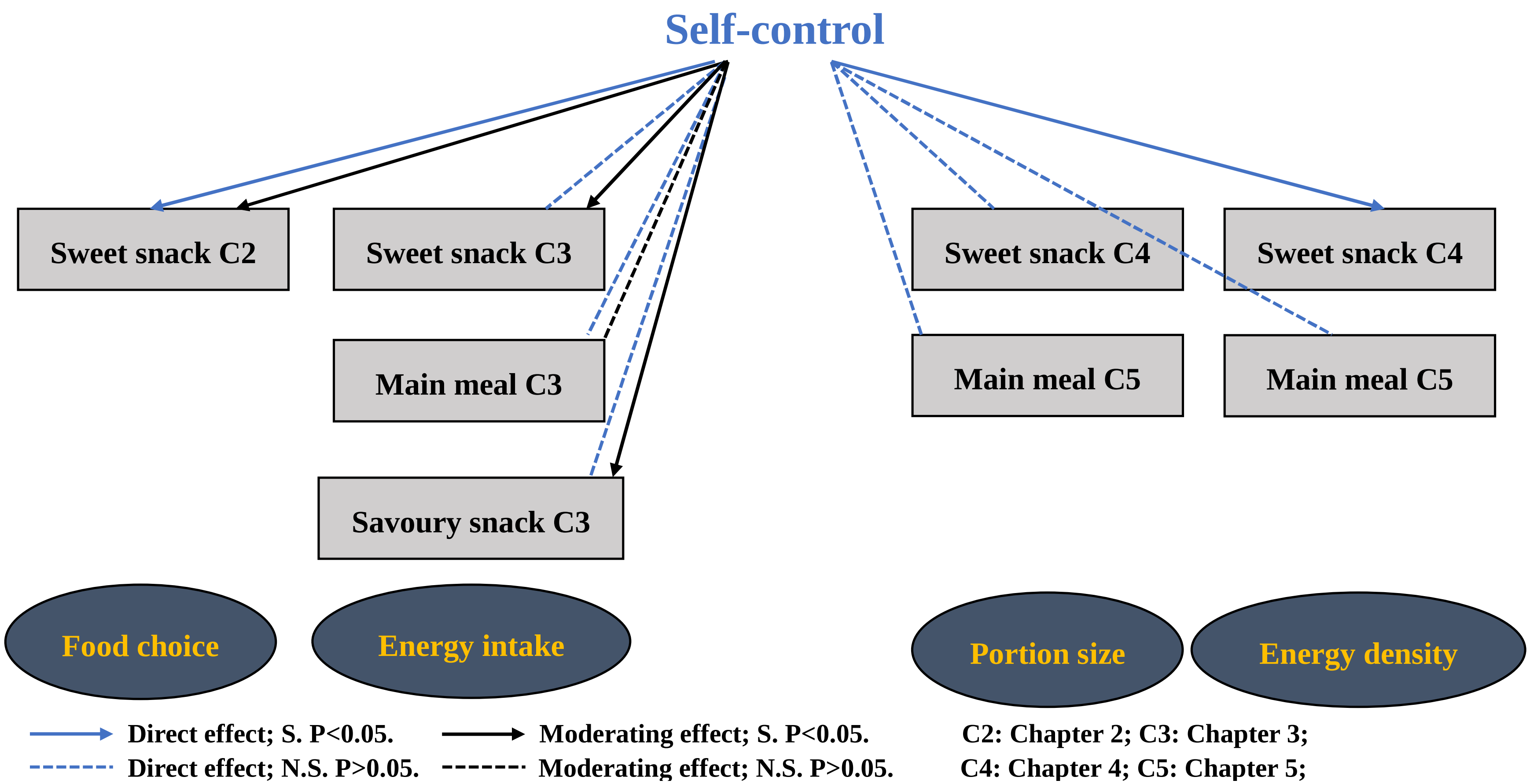

Figure 6.1 – Overview of the findings in the current thesis (Chapter 2, 3, 4 and 5).

6.2 Direct effect of self-control on energy intake and its two determinants (energy density and portion size of food)

The current thesis revealed that general trait self-control (*i.e.* Tangney's Brief Self-Control Scale) does not directly influence energy intake across different eating scenarios (sweet snack, savoury snack, and main meal scenarios) (Chapter 3). Previous studies that examined the direct effect of general trait self-control on food consumption have produced contrasting findings. A previous systematic review suggested self-control is crucial in keeping homeostatic balance (Gerlach et al., 2015). Furthermore, another study suggested general trait self-control was negatively associated with snack energy intake (*e.g.* sweet and savoury snack) (Haynes et al., 2016). These findings indicated that high trait self-control individuals had fewer calories intake compared to low trait self-control individuals (Will Crescioni et al., 2011). However, other studies found that general trait self-control has no direct effect on both sweet (*e.g.* chocolate and cookies) (Hagger et al., 2013; Wang et al., 2015) and savoury snack intake (*e.g.* potato chips) (Friese & Hofmann, 2009; Haynes et al., 2014). Findings from the current thesis corroborate with later that no direct effect of general trait self-control was found on food energy intake. This is in line with the meta-analysis of self-control review that a small effect of general trait self-control was observed on eating behaviour (De Ridder et al., 2012). Inconsistencies relating to the effect of self-control on energy intake in the literature may attribute to individuals' biased estimation of energy content on their selected food and the self-control measure used in eating behaviour research (discussed in section 6.7).

Previous research suggested that the perception of actual energy content in healthy food (*e.g.* low energy density of food) tends to be underestimated, in contrast, unhealthy food (*e.g.* high energy density of food) is perceived in the opposite way (overestimated) (Carels, Harper, & Konrad, 2006; Carels, Konrad, & Harper, 2007). When individuals select food in the presence of multi-foods, individuals are likely to misjudge the energy content of multi-foods in the plate, compared to the only presence of single food (Chernev, 2011; Chernev & Gal, 2010) Such food context may lead to the occurrence of energy illusion due to individuals' unprecise estimation on the total energy of the selected food in their plate. This may be the possible reason to cause no direct effect of general trait self-control on food energy intake across different eating scenarios. This energy illusion in the multi-food presentation has motivated further exploration into the effect of general trait self-control on energy intake.

6.2.1 Self-control on energy density (ED)

The current thesis research is the first to investigate how food self-control influence on energy density (ED) of food in the context of real buffet eating scenarios. Findings from Chapter 4 suggest that food self-control has a significant effect on energy density (ED) of food. In general, findings from the current thesis research suggest low food self-control individuals consumed a significantly higher energy density of food compared to high self-control individuals. This finding is in line with previous studies whereby low food self-control individuals typically make more choices on unhealthy snacks and consume more high energy density food (HEDF) (*e.g.* cheese crackers) (Haws et al., 2016a; Haws et al., 2016b). This evidence suggests that individuals with low self-control have difficulties in inhibiting impulses for instantaneous satisfaction, particularly when being exposed to temptation-related stimuli such as high energy density food (HEDF) (Fishbach & Shah, 2006; Metcalfe & Mischel, 1999). An increased intake of high energy density food is one of the main causes of homeostatic imbalance, which in turn, can lead to weight gain (Blundell & Finlayson, 2004). Such a tendency to increase intake of high energy density food contributed to their unsuccessful weight management for low self-control individuals (Haws et al., 2016a; Haws et al., 2016b).

On the contrary, individuals with high food self-control individuals are more resistant to impulses elicited by temptation-related stimuli such as high ED palatable food

(Fishbach & Shah, 2006). The positive effects of high self-control are evident in healthy eating (Sproesser et al., 2011), fruits and vegetable consumptions (Wills et al., 2007) and high-fat food intake (Gerrits et al., 2010). This evidence confirms that high self-control individuals have less motivational conflicts and are better at avoiding temptation (Hofmann, Baumeister, et al., 2012). According to the dual-motive conflicts model of self-control, individuals were presented with both high and low energy density food that involved trade-offs between two types of motivators: to obtain a smaller, instantaneous satisfaction (pleasure associated with consuming high ED food) or to pursue a bigger, long-term goal (consuming low ED food for successful weight management) (Fujita, 2011). The vice option (high energy density food) presents an impulse for participants who intend to control weight via a healthy diet, since the instantaneous satisfaction from consuming higher ED food conflicts with their longer-term goals. A higher-order weight control goal plays a decisive role in the following coping strategy for high self-control individuals (Fishbach & Shah, 2006). The coping strategies consist of cognitive and behavioural aspects are able to enhance the coherence of intention-behaviour for meeting higher-order goals (Fishbach et al., 2003; Trope & Fishbach, 2005).

The coping strategy is developed based on impulse triggered goal activation (Fishbach et al., 2003). When individuals are exposed into a tempting food cue that can influence the fulfilment of a goal, healthy goal concept will be presented in their mind (Fishbach et al., 2003; Haynes et al., 2014). This healthy goal can be successfully triggered on purposes or through contextual cues (Bargh & Chartrand, 2000; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Kruglanski et al., 2002). Various goals fight for cognitive resources to become aware, assessment of cues in the context that enables subsequent approach or avoidance actions in the direction of serving a higher-order goal (Haynes et al., 2014). Previous studies on goal priming confirm the connection between triggering goal and coherence of following actions towards goals (Haynes et al., 2014). This is consistent with the finding from current thesis research (Chapter 5) that suggest individuals with a stronger body weight control motive consumed a lower energy density of food.

In order to keep goal-consistent behaviour, individuals need resources and make efforts to enable effective self-control on avoiding the tempting food cues (Golan & Bachner-Melman, 2011). Such an effortful control process involved in attentional control and inhibitory or activation control (Nervous et al., 1998). When both high and low energy density foods were presented in front of participants, they view these food stimuli. Individuals with greater self-control pay more attention to virtue food cues instead of vice one, which has been found in current thesis research (Chapter 5). This evidence suggests that higher self-control proactively employed adopting strategies to avoid the possibility of conflicts for the long-term goal since they view the food cues at first glance (Fujita, 2011). Previous research shows that higher self-control is more possible to monitor on their weight goals since they are able to recognise the potential health threats tempting cues offer (Myrseth & Fishbach, 2009; Redden & Haws, 2012). On the contrary, individuals with greater self-control can recognise the virtue option that involves less monitoring; hence they can save resources for the difficult tasks later (Redden & Haws, 2012; Tangney et al., 2004). Greater self-control individuals are more aware when they ought to focus on the action and when they need to rest their attention (Redden & Haws, 2012). They are experienced in adjusting their attentional control over food cues based on the judgements on its threats or benefits to their healthy diet (Haws & Liu, 2016; Redden & Haws, 2012). Attentional control is important for those higher self-control individuals during the meal planning stage, they self-regulate their visual attention towards the healthy food, hence avoiding the temptation from high energy density food (HEDF) and behaving in line with long-term weight control goals (Berridge et al., 2010).

6.2.2 Self-control on portion size (PS)

The current thesis research is the first to investigate how food self-control influences food portion size in a real food buffet setting. Findings from Chapter 4 suggest that food self-control has no direct effect on portion size (PS) of food. Although there is no previous research, relevant studies that assess self-control and portion size have produced a mixture of findings. While some studies observed that triggering self-control concerns had no effect on the following consumption of tempting food when a small packaged format was presented compared to a big packaged format (Coelho do Vale et al., 2008). Other studies found the brain area related to inhibitory control was significantly activated when a large portion of food image was presented (English, Fearnbach, Lasschuijt, et al., 2016). The current thesis research corroborates the former study with no effect of self-control on portion size (PS). Inconsistencies relating self-control and portion size may be influenced by both internal (*i.e.* successfully triggering self-control conflict) and external factors (*i.e.*, multi-food cues, self-serving portion size).

In current thesis research, participants were presented with two high and low energy density foods (Chapter 4, Sweet food: high; chocolate bar and Fudge; low; grape and mandarin; Chapter 5, Main meal: high; French fries and Macaroni cheese; low; Garden salad and Steamed broccoli). Participants were given a plate and asked to select any type of food as much as they would like to eat. Participants were asked to consume the food *ad libitum*; they could refill the plate until the movie ended. When these four types of food are presented to participants, individuals view these food stimuli, they will consider what kind of food they are going to select, determine how much amount of each food they are going to serve during the pre-meal planning stage. If the food stimuli used successfully trigger a self-control conflict during the pre-meal planning, participants would perceive the choices of high energy density food (HEDF) as virtue option, the low energy density food (LEDF) as the vice option for meeting the long-term goal (Haws & Liu, 2016; Liu et al., 2015). Participants with triggering self-control may select more healthy food (e.g. 150g Garden salad) and less unhealthy food (e.g. 50g French fries), they may select a certain amount of healthy food as substitutes of virtue choice to satisfying their hunger. If the food stimuli used unsuccessfully trigger a self-control conflict, participants pick up the tongs to get the first targeted unhealthy food (*e.g.* 150g French fries) and put it into the plate, they will judge whether the current amount of targeted unhealthy food in the plate is appropriate based on perceived portion size, then decide if it is necessary to get more or start to serve other food. Participants will go through the same process for picking up other healthy food (e.g. 50g Garden salad) until finished self-serving. They may have more unhealthy food and less healthy food on their plate. Although individuals with successful trigger self-control may have different food option from those with unsuccessfully triggering self-control, the total weight of food in the plate is same (200g), no matter the food options they have. Therefore, whether trigger self-control or not may have no direct influence on the portion size in such multi-food cues.

Except for the influence of multi-food contexts on pre-meal planning, the food served in the plate may affect the perceived portion size. Participants may perceive the amount of food in the plate as a contextual cue, which may produce visual illusions that possibly prejudice judgments on the perception of portion size and following action for serving another food (Van Ittersum & Wansink, 2007). Previous research systematically explains how both horizontal and vertical illusion influence on portion size estimation by misjudging the extent of a horizontal dimension with respect to a vertical dimension (Inhelder, Piaget, & Szeminska, 1960; Piaget, 2013). Further studies have revealed that this illusion significantly influences how portion size (PS) individuals serve and eat (Raghubir & Krishna, 1999; Wansink & Van Ittersum, 2003). Therefore, food served on the plate may distort the judgement of portion size. Previous studies which assessed the portion size effects for multi-food items found that no difference was presented in perceived portion size for different multi-foods (entrée and desserts) in terms of different eating scenarios (breakfast, lunch and dinner) (Kral et al., 2003). It may be more difficult for participants to correctly identify the perceived portion size for each type of food in the plate in a multi-food condition compared with a single food one

(Kral, 2006). This evidence may contribute to individuals' insensitivity towards appropriate portion size judgements.

Habitual portion size as an important aspect may contribute to the total amount of food during the self-serving process. Possibly, participants have different habitual portions for each type of food (Kral, 2006). If the self-control conflict was not successfully triggered, participants may determine the amount of each food to serve based on the habitual portion size in previous consumption experience (Brunstrom, 2014; Kral, 2006). Previous research on the self-serving study found that the majority of participants could finish the entire meal in self-serving portion, which reached up to 90% (Brunstrom, 2014). This evidence further suggests that habitual portion size play an important part in determining food portion size at the self-service that determines the following food consumption. A more comprehensive method is necessary to measure how individuals perceive the portion size that is associated with their habitual portions. In a future study, it would be useful to further explore how learning mechanisms develop individuals' habitual portion size from consumption experience in their lifetime (Brunstrom, 2014; Kral, 2006). It would be interesting to employ 'habitual food portion' as a reference portion to assess what contexts could successfully trigger self-control on the portion size or indulgent eating in different eating scenarios.

Previous intervention studies on activating self-control by downsizing food portions in three field tests showed that participants who accepted smaller portions did not reduce calories in their entrée ordering (Schwartz et al., 2012). This evidence further suggests the effective triggering self-control conflict may not prompt individuals to continuously implement self-control for the following food consumption. As such, they will not trigger the coping strategies that could restrict their food consumption (Fishbach & Shah, 2006). Participants from the assumed tendency to believe that having smaller quantities of tempting food is "acceptable" (Coelho do Vale et al., 2008). This is supported by a series of experiments regarding a restrained eating behaviour study, which found restrained eaters had more food intake in small packaged formats compared to unrestrained eaters with more food consumption in a large packaged format (Scott et al., 2008). Indulgent eating even in a small packaged format may lead to self-control failure for restrained eaters. This evidence suggests how a small amount of tempting food can remain unnoticed (Coelho do Vale et al., 2008).

6.3 Direct effect of trait self-control on food choice

Findings from the current thesis research (Chapter 2) suggested both explicit (*i.e.* Tangney's Brief Self-Control Scale) and implicit measure (*i.e.* single-target implicit association test) of self-control did not correlate each other, and they can independently predict food choice, adding to the existing evidence for reflective and impulsive systems in determining individual behaviour (Hofmann et al., 2009; Keatley et al., 2017; Strack & Deutsch, 2004). As such systems have been exhibited in a wide range of disciplines particular in psychology (personality and social) (Metcalfe & Mischel, 1999; Smith & DeCoster, 2000). Although dissimilar terms have been applied to define the dual systems in psychology, such models reveal the hypothesis that the distinct information processing of these two systems prompts the formation of reflective and impulsive behaviour (Hofmann et al., 2009). Previous brain-imaging studies have suggested that these two systems activated different brain regions (Bechara, Noel, & Crone, 2006; Lieberman, 2007). This evidence constructs the classic view of dual systems that one of the two systems is involved in a given context (Hofmann et al., 2008). The perspective of the latest research suggested that both systems may be activated concurrently (Hofmann et al., 2009). Strack and Deutsch (2004) reviewed how the reflective impulsive model (RIM) compete and interact to predict behaviour. The latest studies have suggested that self-control involved these two systems (Keatley et al., 2017).

Food behavioural forced-choice response (BFCR) as an eating behaviour measure was used in the current thesis research. During this task, participants were presented with a pair of food image randomly selected from either the high or low energy density food category. They were instructed to select the food they “most want to eat now” as quickly as possible (Dalton & Finlayson, 2014). The notion of these choice settings is that most individuals would perceive one of the choices as instantaneous satisfaction, impulsive, and a vice choice and the other as the choice that is associated with long-term goal-oriented, controlled, or virtuous behaviour (Haws & Liu, 2016; Liu et al., 2015). Low energy density food (LEDF) is used as the stimulus of a lower temptation, which is more likely to activate deliberate behaviour. As previous studies suggested, implicit measures are more sensitive to automatic behaviour triggered by high temptation (Asendorpf et al., 2002; DeCoster et al., 2006; Smith & DeCoster, 2000; Strack & Deutsch, 2004). Therefore, such food choice measures may involve either reflective and deliberate systems, or correspondingly engage the impulsive and automatic systems. Such dual systems in determining behaviour are well studied in social psychology (Chaiken & Trope, 1999; Hofmann et al., 2009; Hofmann et al., 2008; Strack & Deutsch, 2004).

Previous research about how to assess an impulsive system has produced a mixture of conclusions. While Hofmann, Friese, and Wiers (2011) suggest implicit methods (implicit association task) as the most suitable measurement tool which can capture responses from the impulsive system. Other researchers such as Conner, Prestwich, and Ayres (2011) and Gibbons, Kingsbury, Gerrard, and Wills (2011) recommend that the impulsive system can be measured by explicit (self-reported measure) methods. For instance, Eysenck and Eysenck (1978) proposed explicit methods of impulsiveness with the high predictive ability for behaviour (substance usage) (Bickel et al., 2007; Wills, Sandy, & Yaeger, 2000). Conner et al. (2011) and Gibbons et al. (2011) quote several latest studies and re-analyses the data from previous research, illustrating that effective self-reported measure may often perform better than implicit measures with a greater predictive ability on behaviour prediction. This evidence suggests that affective self-reported measure is likely to tap into the impulsive system on influencing behaviours (Conner et al., 2011; Lawton, Conner, & Parker, 2007). According to the view from Hofmann et al. (2011), implicit measures may offer an alternative for the assessment of initial ‘upstream’ phase. Nevertheless, another landing phase may also occur, such as ‘downstream’ phase that can be captured via self-reported measure (Hofmann et al., 2011). Therefore, appropriate explicit (self-reported measure) and implicit methods (implicit association task) seem to be workable for assessing impulsive systems (Conner et al., 2011; Hofmann et al., 2011). Findings from the current thesis research (Chapter 2) support the views from both. Implicit measure (single-target implicit association test) offers an alternative for the assessment of self-control, which can successfully predict food choice. However, the self-reported measure did perform better than implicit measures with the greater predictive ability on food choice prediction in the current thesis research.

In terms of the intervention strategy, Hofmann et al. (2011) suggest that re-shape impulsive system is workable to decrease impulse on behaviour. Several studies have generated further evidence that impulsive process is able to be re-shaped for problematic targeting groups such as using evaluative conditioning (Houben, Schoenmakers, et al., 2010; Wiers, Rinck, Kordts, Houben, & Strack, 2010) and attentional retraining (Fadardi & Cox, 2009; Schoenmakers et al., 2010). Gibbons et al. (2011) agreed that this intervention technique as an alternative seems to be promising. However, they argued that such a technique is to some extent unfeasible, and it seems to be ineffective for targeting groups such as young people. This intervention technique will be more workable in such situations that maladaptive associations have been previously built (Gibbons et al., 2011). Findings from the current thesis research (Chapter 5) indicate the significant interaction between training groups and sessions. This finding corroborated with the former study that IAT training affects eating behaviour, which added the existing evidence about the effectiveness of modifying impulsive system on behaviour change (Ebert et al., 2009; Lebens et al., 2011). The possible reason may be the automatic associative learning mechanism in the targeted

IAT training successfully activate participants' long term-goals (weight management). During this IAT training task, participants were asked to consistently pair female body images with food images. This learning process can build new associations between the high energy density of food and fat figure, and associate low energy density of food with lean figure. Such learning process may remind their long-term goal. Thus, low self-control individuals from the targeted training group did not act the same way as the control group –significantly increase portion size of food in subsequent food consumption. Thus, findings suggest that IAT training affects eating behaviour. Although this IAT training was found to effectively modify the impulsive system on eating behaviour change, such training showed no acute effect on significantly reducing the portion size and energy density of food. The limited sample size may restrict the generalisability of this conclusion. Future research should replicate the current findings with a large sample size.

6.4 Moderating effect of general trait self-control on food choice and energy intake

Findings from the current thesis showed that general trait self-control moderated the relationship between disinhibited eating and food choice (Chapter 2) and energy intake (Chapter 3). Specifically, data from the current thesis research also suggest that self-control significantly moderated the relationship between disinhibited eating and behavioural forced-choice response and food intake towards high energy density food (HEDF) (Chapter 2: sweets; Chapter 3: ice cream) among individuals with high self-control. In addition, self-control significantly moderated the relationship between disinhibited eating and chips energy intake via hedonic responses among low self-control individuals (Chapter 3). Findings from the current thesis are consistent with previous studies whereby individuals with high food self-control often choose low-energy, healthy food in relative to those with low self-control (Haws et al., 2016a; Haws et al., 2016b). This evidence further substantiated the existence of dual-motive conflicts model of self-control that represents a conflict between instantaneous satisfaction (*e.g.* taste) and long-term goals (*e.g.* weight control) (Fujita, 2011). High and low self-control individuals differ in their motives and propensity to exhibit different levels of self-control in food choice decision (Hofmann, Baumeister, et al., 2012). While high self-control individuals endeavour to act in line with their long-term goals, they deem food healthiness and taste as predominant during the meal planning stage (Hare, Camerer, & Rangel, 2009). However, due to no existence of weight control goals in mind, food taste rather than heathenness has been identified as a primary driver for low self-control individuals when they make food choice decision (Sullivan et al., 2015). Previous studies suggested that healthiness judgments were moderated by individual differences in self-control, high self-control individuals made healthiness judgments that promote healthier food choices compared to low self-control individuals (Davis et al., 2013). During the consumption stage, high self-control individuals satiated quicker on unhealthy snack consumption against healthy one compared to low self-control individuals (Redden & Haws, 2013). These findings indicate that effective self-control facilitates healthy diet by regulating predisposition to high energy density of food (Hofmann, Baumeister, et al., 2012)

6.5 Top-down and bottom-up processes

Tempting high energy density food (HEDF) often hinders individuals' fulfilment of long-term weight management goals, although individuals intend to avoid these tempting food cues (van Koningsbruggen et al., 2017). Previous literature suggests that this is partially due to tempting high energy density food (HEDF) automatically triggering a bottom-up food reward process or hedonic processes that override the influence of top-down impulse control process, or self-control on behaviour (Hofmann & Van Dillen, 2012; Kruglanski et al., 2002; Nigg, 2017). Earlier studies proposed that behaviour associated with the pursuit of multiple goals may be guided by these two processes (Kruglanski et al., 2002). In a top-down impulse control process, individuals who proactively control their behaviour refer to earlier formed goal criteria (***i.e.*** weight management goals) and select which behaviours can help them meet their present goal criteria (***i.e.*** avoid tempting food) (Nigg, 2017; Rauss et al., 2011). This proactive control might involve different strategies to prevent temptation, which could be automatic or habitual behaviours (avoiding high energy density food options), but could also be intentional actions (filling up on healthy snacks to prevent hunger-driven snacking later) (Braver, 2012). Such a top-down process is more likely to occur on individuals with high self-control, which was found in Chapter 2, 3, and 4 of current thesis research. In a bottom-up food reward process, reward properties of high energy density palatable automatically trigger hedonic responses, which can elicit strong eating impulses (*i.e.* taste goals) (Hofmann, van Koningsbruggen, Stroebe, Ramanathan, & Aarts, 2017; Stroebe, Mensink, Aarts, Schut, & Kruglanski, 2017). Difficulties in inhibiting such impulses activate an approach behaviour towards these tempting food cues, which may cause self-control goal failure (Hofmann & Van Dillen, 2012; Seibt et al., 2007; Veenstra & de Jong, 2010). Such failure is more likely to occur in individuals with low self-control, which was found in Chapter 2, 3 and 4 of the current thesis research.

6.5.1 Top-down processes

Findings from the current thesis research showed that self-control had an effect on the energy density of food (Chapter 4). In addition, self-control moderated the relationship between disinhibited eating and food choice (Chapter 2) and food consumption (Chapter 3). Specifically, high self-control individuals had a significantly lower energy density of food intake (Chapter 4). Data from the current thesis research also suggest that self-control significantly moderated the relationship between disinhibited eating and behavioural forced-choice response and food intake towards high energy density food (HEDF) (Chapter 2: sweets; Chapter 3: ice cream) among individuals with high self-control. This evidence added to the existing evidence that top-down control processes act as critical goal guidance for regulating eating behaviour (Heatherton, 2011; Hofmann, Schmeichel, et al., 2012). The goal guidance of top-down process promotes behavioural consistency with goal pursuit (Fishbach & Dhar, 2005). Such a process successfully activates goal monitoring schemes that ensure the following actions can meet goal criteria (Laran & Janiszewski, 2008). The determining factor of behaviour consistency in two continuous actions is dependent on the first action on the goal commitment (Fishbach & Dhar, 2005).

When individuals recognise the first act as a commitment to the goal, they would probably engage in the same goal when they make a second decision on the following behaviour (Fishbach & Dhar, 2005; Fishbach, Dhar, & Zhang, 2006). For instance, high self-control individuals are more aware of their weight control goals when they are exposed to tempting desserts after dinner. They are able to skip the instant gratification from the tempting desserts in order to achieve their long-term weight management goals (Hofmann et al., 2008). The top-down impulse control process is more likely to be automatically triggered by tempting desserts for these high self-control individuals because they had previous experiences in being able to resist such food temptations (Fishbach et al., 2003). It is, therefore, easier for high self-control individuals to carry out top-down impulse control in order to achieve their weight management goals since they faced fewer motivational conflicts (Büttner et al., 2014; Hofmann, Baumeister, et al., 2012).

6.5.2 Bottom-up processes

Findings from the current thesis research suggest that chips hedonic responses significantly mediated the relationship between disinhibited eating and chips consumption (Chapter 3). This signifies that individuals with higher disinhibited eating experience a high hedonic response to chips, then indulge in unhealthy chips consumption. This finding added to the existing evidence of a bottom-up food reward process which drives the food intake (Gerlach et al., 2015; van der Laan & Smeets, 2015). High energy density food (HEDF) as motivational cue can generate a robust effect on attention (Higgs et al., 2015). The power of these food cues to draw individuals' attention could be related to its rewarding properties (Castellanos et al., 2009; Knudsen, 2007). The bottom-up process requires information collection on incentive salience properties of tempting food (*i.e.*, sensory properties, palatability) (Castellanos et al., 2009; Knudsen, 2007; Robinson & Berridge, 1993). This bottom-up manner may potentially bias individuals' perceptions of food cues, which enable individuals to process high energy density food (HEDF) preferentially over low energy density food (Field, Munafò, & Franken, 2009). This tendency automatically elicits strong eating impulses towards high energy density food (HEDF) (Seibt et al., 2007; Veenstra & de Jong, 2010). This eating impulse is directed onto an instantaneous satisfaction, which usually involves a tendency to carry out a specified behaviour such as an inclination to approach high energy density food (HEDF) (Ainslie, 1975). If individuals carry out such behaviour with no control, their behavioural implementation may operate effortlessly for meeting an instantaneous satisfaction even without deliberately noticing. Following such impulses is more likely to be the easiest and most common matter in such food contexts, which may contribute to the difficulty in self-control (Hofmann et al., 2009).

Findings from the current thesis research showed that low self-control individuals had a higher energy density of food intake (Chapter 4) and more HEDF choice (Chapter 2). In addition, self-control significantly moderated the relationship between disinhibited eating and chips intake via hedonic responses among low self-control individuals (Chapter 3). These findings added the existing evidence of a bottom-up food reward process on driving the food intake, which is more likely to occur in low self-control individuals (Haws & Redden, 2013). Individuals with low self-control experienced stronger hedonic responses towards high energy density food (HEDF) (Bryant et al., 2008; Keeler et al., 2015). Impulses for instantaneous satisfaction are driven by the hedonic response when individuals are exposed to tempting food (Metcalfe & Mischel, 1999). Difficulties in inhibiting such impulses unintentionally trigger approach behaviour towards high energy density food (HEDF) (Metcalfe & Mischel, 1999), especially for individuals with low self-control (Gillebaart & Ridder, 2015). They may naturally perform such behaviours for meeting an instantaneous satisfaction without conscious notice (Naets et al., 2018; van den Bos & de Ridder, 2006). Low self-control individual follows such impulses to act on behaviour seems to be the most common thing in such an obesogenic environment, which may contribute to their self-control failure (Hofmann et al., 2009). Previous research observed low self-control individuals had a higher desire for more food and increased food intake in the presence of multi-foods (Haws & Redden, 2013). Indulging in high energy density food (HEDF) intake fulfils instantaneous satisfaction, which contributes to homeostatic energy imbalance and weight gain (De Ridder et al., 2012; Metcalfe & Mischel, 1999).

6.6 The strength model of self-control

The current thesis revealed that hunger has no relationship with food choice (Chapter 2), energy intake (Chapter 3), portion size and energy density (Chapter 4). Previous studies that assessed the effect of hunger on eating behaviour has produced a mixture of findings. While some studies found that hunger as a physiological factor have effects on the amount of food people purchase and consume (Mela et al., 1996; Nisbett & Kanouse, 1969) especially in meal initiation (Stubbs et al., 2000). However, other studies showed no relationship between energy intake and hunger level (Fay et al., 2015). Findings from the current thesis corroborate the latter with no association between hunger and eating behaviour in food choice, energy intake, portion size and energy density. Which is true in many situations such as eating without hunger and binge eating, people eat when they are not hungry (Fay et al., 2015).

Prior research showed the relationship between energy depletion and reduced self-control, indicated fasting state facilitates enhancive impulsive actions (DeWall et al., 2011). The neuro-image study has been observed that fasting augmented rewarding regions in the brain when exposed to high energy density food (HEDF) (Siep et al., 2009). However, data from the current thesis research (Chapter 4) suggested that no difference exists between fasting and non-fasting conditions in portion size and energy density of the food. This is consistent with a previous food deprivation study on eating disorders, which found that there was no increase in food consumption for those people without eating disorders (control group), after 19 hours fasting (Hetherington et al., 2000). The latest research on food deprivation suggested that 24 hours of fasting failed to cause an increase in food intake for the next four days ad libitum sessions (Levitsky & DeRosimo, 2010). This evidence is inconsistent with literature, which has found that skipping meals did not cause adequate compensation for the decrease in food intake (Levitsky, 2005). Findings from the current thesis research suggest that people are not able to accurately compensate for energy loss caused by fasting through having more energy intake later, even when faced with food deprivation (Heilbronn et al., 2005; Levitsky & DeRosimo, 2010).

Baumeister and his colleagues proposed the strength model of self-control that the performance of self-control operates on the basis of a limited resource (Baumeister et al., 1998; Baumeister, Vohs, et al., 2007). Self-control is a global strength or energy resource that facilitates individuals to participate in tasks and acts that involve self-control (Muraven, Tice, & Baumeister, 1998). Nevertheless, the strength or energy resource is posited as limited and susceptible to turning into depleted through use over time (Baumeister et al., 1998). As such depleted conditions can give rise to self-control failure, such that individuals fail to effectively put in endeavours to resist desires, tempting stimuli and impulses (Baumeister et al., 2000). Like a muscle that needs the energy to execute an action and become exhausted after continuous exertion, individuals are able to apply self-control just for a limited time interval and their energy is susceptible to be depleted as times goes by (Baumeister, Vohs, et al., 2007). Likewise, just as muscles need a while to rest or recover before further exertion, further execution of self-control can only be achieved after a while of resting or recovery. The failure of self-control is attributed to the depletion of self-control resources (Baumeister et al., 1998). Increasing evidence on the strength model of self-control has been examined in various health-related behaviours (Hagger et al., 2009). However, this evidence of the strength model of self-control has been targeted on state view and investigated how short-term depletion effect attenuated the performance of the following tasks that demand self-control ability (Hagger et al., 2013). Psychological studies suggest that self-control emerges as two distinguishable types, involving the state and trait (Tangney et al., 2004). State self-control will change with the individual's emotional state, the surrounding environment and the physiological conditions (Ackerman et al., 2009; Hagger et al., 2010; Salmon, Adriaanse, et al., 2014). In contrast, trait self-control is an individual's stable personality tendency that does not change with time and context (Gillebaart et al., 2016; Moffitt et al., 2011; Wang et al., 2015). The current finding supports the view from Tangney and her colleagues that the trait of food self-control is an individual's relatively stable personality tendency (Tangney et al., 2004). It does not change with physiological conditions such as fasting states.

6.7 Methodological consideration for measuring self-control

The current thesis research is to systematically test for the role of self-control in determining individuals' eating behaviour. Specifically, the thesis examines the role of self-control in influencing an individual's food choice, energy intake, portion size and energy density, in different eating scenarios by applying two self-control measures that include general trait self-control (***i.e.*** Tangney's Brief Self-Control Scale) (Chapter 2 and 3) and domain-specific self-control (***i.e.*** Food Self-Control Scale) (Chapter 4 and 5) measure. The current thesis revealed that general trait self-control (***i.e.*** Tangney's Brief Self-Control Scale) does not directly influence energy intake across different eating scenarios (sweet snack, savoury snack, and main meal scenarios) (Chapter 3). Inconsistencies relating to the effect of self-control on energy intake in the literature may attribute to the self-control measure (***i.e.*** Tangney's Brief Self-Control Scale) used in Chapter 3. This condition poses a dilemma in which self-control measures (general or domain-specific) are most applicable to different eating scenarios. The construct of trait self-control as a general measure applies in different disciplines rather than targeting any specific eating domain. A consideration of self-control ought to be capable of interpreting chronic tendency to exhibit self-control within a targeted domain and across different domains. For instance, an individual who has high trait self-control ought to have high self-control when it comes to spending and eating, due to the ability to access into and operate on the basis of the same resource pool. Such a consideration of self-control indicates that high self-control in one targeted domain will imply high self-control in other domains.

The previous study suggested that there was not much difference between struggling in control spending money and regulate food consumption (Faber, Christenson, De Zwaan, & Mitchell, 1995). However, the latest research proposed that a domain-specific measure of health-related control, with a focus on predicting health behaviour (Gomez, Borges, & Pechmann, 2013). Haws et al. (2016b) suggest that personal previous experience may influence the self-control operation in different domains, and general measure is less possible to employ specific domain settings.

Control over food choices and the portion size has turned into a major problem in the field of eating behaviour, with obesity becoming prevalent all over the world (Flegal, Carroll, Kit, & Ogden, 2012; Zobel, Hansen, Rossing, & von Scholten, 2016). The previous study has demonstrated how drastic changes to the food environment such as portion sizes (PS) and energy density (ED) affect the amount of food an individual consumes, or how these factors affect indulgent eating (Duffey & Popkin, 2011; Kral & Rolls, 2004). One main suggestion from the broad studies on food self-control is that a variety of factors influence eating behaviours such as internal (*e.g.* hunger) and external factors (*e.g.* food cues and palatability) (De Ridder et al., 2012; Herman & Mack, 1975; Wansink, 2006; Wardle, 1987). As a result, these factors may contribute to individual differences in eating behaviour. Such individual differences may cause difficulties in finding the association between food self-control and eating behaviour (Haws et al., 2016b). Such difficulties may lead many scholars to apply general trait self-control measures in food-related studies (Haws et al., 2016b; Laran, 2009; Redden & Haws, 2012).

Previous studies have recognised some domain-specific aspects of self-control in determining an individual's differences in a specific domain (Haws, Davis, & Dholakia, 2016b). In numerous respects, eating behaviour can be predicted by a specific measure of individual self-control, which further reveals the relationship between individuals' responses towards that specific domain and domain-specific self-control (Haws, Davis, & Dholakia, 2016b). Take eating domains as an example, Haws et al. (2016b) used both Tangney's Brief Self-Control Scale and Food Self-Control Scale to examine the predictive relationship between self-control and food choice. The results showed that food self-control (FSC) can explain an additional 10.2% of the explained variance in terms of predicting food choice compared to Tangney's Brief Self-Control Scale. This study suggests that food self-control (FSC) could facilitate greater insights into various eating scenarios than general trait self-control (Haws, Davis, & Dholakia, 2016b). The positive result showed that the food self-control measure is more effective for predicting eating behaviours (***i.e.*** virtues and vices food choices) compared with general trait self-control (Giner-Sorolla, 2001; Haws et al., 2016b). The positive effects of food self-control are evident in healthy eating across different food types and eating scenarios (Haws et al., 2016a; Haws et al., 2016b). This evidence suggests that food self-control (FSC), regarded as a validated self-reported measure, could be particularly useful for capturing individual differences in different eating behaviours (Haws et al., 2016a; Haws et al., 2016b). Therefore, the food-specific self-control measure is recommended to use in eating behaviour research as opposed to the general trait self-control measure, as the former is thought to can capture the specific food-related self-control conflict (i.e., between taste and health) more effectively.

6.8 Methodological consideration for measuring eating behaviour

A key point for an effective eating behaviour measure in self-control related research is that participants ought to recognise the conflicts to be involved with the usage of self-control. This rule has been commonly used in previous self-control research across a range of domains (Haws et al., 2016a). Some self-control related studies measure eating behaviour using a healthy (virtue) and unhealthy (vice) food choice methodology. Participants were presented with a series of food choices (consist of both healthy and unhealthy food items), they were instructed to select the most preferred food choice (Haws & Liu, 2016; Liu et al., 2015). Such a method usually involves food images or real food choice settings. Other methods applied to measure eating behaviour in self-control related research is food consumption. Participants were asked to consume the food *ad libitum* (Haynes et al., 2016; Kirk & Logue, 1997). The current thesis research used both choice (real food choice, Chapter 4; graphical food choice, Chapter 2) settings and quantity consumption measures (Chapter 3, 4 and 5) as eating behaviour measures. These measures pose a dilemma of which eating behaviour measures are most effective in triggering self-control conflict.

6.8.1 Food choice measures

Food choice measure allows individuals to make decisions between two choices, which involve trade-offs between instantaneous satisfaction and long-term goals. Shiv and Fedorikhin (1999) employed a trade-off between cake and salad on the basis of food perception. Other classic trade-offs employed in the food-related research consist of sweet snacks versus fruits (*e.g.* cookies and apples) (Gal & Liu, 2011; Garg et al., 2007; Liu et al., 2015), savoury food versus vegetable (*e.g.* fries and carrots) (Liu et al., 2015), healthy bar versus unhealthy bar (*e.g.* sweets versus granola bars) (McFerran et al., 2009), to name just a few. These trade-off stimuli are usually selected based on the preliminary test or previous studies. The notion of these choice settings is that most individuals would perceive one of the choices as instantaneous satisfaction, impulsive or a vice choice and the other as the choice as long-term goals oriented, controlled, or virtuous behaviour (Haws & Liu, 2016; Liu et al., 2015). The food choice stimulus used in the current thesis research consisted of both graphic (Chapter 2) and real sweet food (Chapter 4). The sweet food choice settings in these two Chapters involved high (*e.g.* chocolate bar) and low (*e.g.* grapes) energy density food. Findings from Chapter 2 show that general trait self-control has a direct effect on food behavioural forced-choice responses towards high-calorie foods. In addition, findings from Chapter 4 reveal that food self-control is associated with energy density (ED) of food choice. This evidence suggests that both graphic and real sweet food choice settings that involve high and low energy density food are effective for triggering self-control conflict.

6.8.2 Food consumption measures

Another common method used to measure eating behaviour is food consumption. This measure quantifies the amount of food consumed (Haws et al., 2016a). The concept for this measure is that individuals exert higher self-control would have a lesser amount of high energy density food (HEDF) intake (Haws et al., 2016a). Extensive research has achieved consensus that having small amounts of food indicates high self-control as opposed to eating a large amount of a high energy density food (HEDF) (De Ridder et al., 2012; Wang et al., 2015; Will Crescioni et al., 2011). These high energy density food (HEDF) stimuli used in the food-related research consist of sweet snacks (***e.g.***, dessert, candies, cookies) and savoury food (***e.g.*** chips) (Dewitte et al., 2009; Haynes et al., 2016; Zhang et al., 2010).

The real food stimulus used in the current thesis research consisted of sweet food (Chapter 2, 3 and 4), savoury snack (Chapter 3) and the main meal (Chapter 3 and 5). In general, both sweet food and savoury snack can successfully trigger the effect of self-control (only moderating). However, the main meal was not effective in triggering both direct and moderating effect of self-control. Therefore, whether the self-control process can be captured may depend on the food types. The latest study found the different decision-making processes between desserts and main dishes for food choice (Wang et al., 2018). This evidence suggested that the decision-making can vary considerably across food types (***i.e.***, sweets vs. main meals) (Graham et al., 2011; Wang et al., 2018), which engaged different processes of rewards, emotion and cognitive functioning (Rangel, 2013; Rolls & Grabenhorst, 2008). For instance, individuals may perceive the main meal (***e.g.*** pasta) as the course of the meal to satisfy their hunger. As such, individuals may perceive the main meal with less complex decision process compared with other types of food. This may be the reason the moderating effect of self-control was found in both sweet food and savoury snack, but not in main meal scenario. It goes without saying that some internal and external factors possibly influenced the amount of food consumed. These factors make self-control more difficult in capturing self-control conflicts when involved with real food consumption. It is necessary that the selection of food stimuli should trigger a self-control conflict. For this reason, it is highly recommended that both sweet food and savoury snack are able to capture self-control conflicts rather than the main meal. Due to a limited number of food stimuli used in the current thesis research, in the future study, it would be useful to further explore whether other types of sweet food and savoury snack can successfully trigger self-control conflicts in the food consumption scenarios.

6.8.3 Food consumption versus choice measures

For individuals who would perceive the option settings as a self-control conflict, it is essential to think about whether the choice measure is effective or whether real food is needed in assessing assumptions associated with food-related self-control (Haws et al., 2016a). Prior research found that both graphical and real food testing formats are effective in eliciting motivational desire, and consistent results were found in both measures (Shiv & Fedorikhin, 1999). This is consistent with the findings from Chapter 4 that food self-control has a direct effect on both food choice (ED choice) and food consumption (ED intake). These two eating behaviours in Chapter 4 involved both high (*e.g.* chocolate bar) and low (*e.g.* grapes) energy density food. The consistent findings (Chapter 4) between food choice and food consumption suggest that high and low energy density food settings in both tasks are effective in triggering self-control conflict.

Latest research suggested high and low energy density food choice scenarios can perform better than other eating behaviours (*i.e.* only involved in high energy density food consumption; cheese cracker) to capture an individual’s difference in self-control conflict (Haws et al., 2016a; Haws et al., 2016b). This is consistent with the findings from Chapter 2 and 3 that general self-control has a direct effect on food behavioural forced-choice responses (involved in high and low energy density food), but not directly influence energy intake across three eating scenarios (***i.e.*** only involved in high energy density food; chips). The inconsistent findings (Chapter 2 and 3) between food choice and food consumption may attribute to the different food consumption settings in Chapter 3 (high energy density) and 4 (high and low energy density). The decision-making process in the context of only high energy density food may less involve self-control process and more involve avoidance of unhealthy (vice) food. From the theoretical point, self-control might involve different strategies to prevent temptation, which could be automatic or habitual behaviours (avoiding high energy density food options), but could also be intentional actions (filling up on healthy snacks to prevent hunger-driven snacking later) (Braver, 2012). Therefore, it is highly recommended that eating behaviour measure (food consumption and choice) applied to signify self-control conflicts ought to comprise one unhealthy (vice) food option that the participants perceived to be desirable (instantaneous satisfaction), and one healthy (virtue) food option that the participants find comparatively less appealing (weight management) (Haws et al., 2016a). As such, high and low energy density food settings enhance the possibility of triggering self-control conflict more easily so that the eating behaviour measure is able to reflect the degree of conflicts for that person.

6.9 Limitations and future study

The limitation of each study has been discussed in each sperate chapter. Overall, there are a number of limitations in the current thesis research. First of all, the sample only included female participants within a young age range (Chapter 3, 4 and 5), which may restrict the generalisability of the current conclusions. In order to increase its generalisability, in future studies, it would be useful to further replicate present findings with diverse socioeconomic or demographic factors (***e.g.***, gender, age, subculture group and economic group). Take gender as an example, previous studies suggest that the portion size effect has been found in males (Burger, Fisher, & Johnson, 2011; Rolls, Morris, & Roe, 2002). The latest research suggests that the portion size effect was greater in males than in females (Zlatevska et al., 2014). Even though systematic review shows the influence of self-control is equally strong in both males and females for the desired behaviour, the effect of self-control on the performance of undesired behaviour inhibition in males was greater than females (De Ridder et al., 2012). Therefore, it would be useful to explore possible gender differences in terms of the effect of self-control in determining an individual's eating behaviour in future studies. Moreover, the previous review showed that the age of the tested population had a significant influence on the relationship between self-control and behaviour (De Ridder et al., 2012). The greater influence of self-control was found in a younger age range, which indicated the effect of age on the relationship between self-control and food consumption likely to be smaller in other age range samples (De Ridder et al., 2012). It also would be interesting to investigate whether the effect of age existed on the association between self-control and different eating scenarios. In order to increase the generalisability of the current conclusions, it is essential to extend present findings in a future study with diverse socioeconomic or demographic factors.

Secondly, the current thesis research was only carried out in a laboratory-based test. Although diverse food stimuli were tested in a laboratory consisting of sweet food (Chapter 2, 3 and 4), savoury snack (Chapter 3) and the main meal (Chapter 3 and 5), it remains to be examined whether the current findings generalise the effect of self-control on different eating scenarios in the "real world". Therefore, in future studies it would be useful to determine ecological validity with other food types, using different eating scenarios in the field test. Previous studies suggest that ecological momentary assessment (EMA) as a real-time data collecting technique was initially established in psychological research (Dunton, 2011; Liao, Skelton, Dunton, & Bruening, 2016). EMA refers to sampling approaches that examine events on the occasion they happen in natural set-up (Shiffman, Stone, & Hufford, 2008). Prior research applied the EMA approach to capture participants' real-time responses in assessing the interaction between personal and environmental predictors for predicting overeating behaviour (Thomas, Doshi, Crosby, & Lowe, 2011). Advantages of this research not only involve the employment of EMA to examine the real-time response of individuals in their natural settings but also include analytic techniques that model participants' repetitive measurements (Liao et al., 2016). Furthermore, the findings from EMA technique are deemed to increase generalisability compared with the data acquired from a lab test, due to the fact that real-time response of individuals is captured in their natural settings (Stone et al., 2007). Such technique is able to capture more insights into whether the effect of self-control on different eating scenarios found in the current thesis research can be replicated in "real-world" settings while decreasing the limitations of the laboratory-based test.

Finally, the self-control measures (***e.g.*** food self-control) in the current thesis research were implemented before (Chapter 2, 4 and 5) and after (Chapter 2 and 3) the eating behaviour measure (***e.g.*** food choice), it is likely that the testing sequence may have an influence on individuals' responses on the self-control measure and eating behaviour. For instance, the self-control measures (***e.g.*** food self-control) in Chapter 5 have to be tested before the eating behaviour measure, due to only targeting the intervention for low self-control individuals. Such testing sequence may prime the notion of "impulsivity", which has been observed to influence following energy intake (Guerrieri, Nederkoorn, Schrooten, Martijn, & Jansen, 2009). On the contrary, the self-control measures (***e.g.*** explicit self-control) in Chapter 3 were implemented after the ***ad libitum*** session, this testing sequence has an influence on individuals' responses on the self-control (Haynes et al., 2015). Therefore, in future studies, it would be useful to counterbalance the order of all tested measures that more robust conclusions can be drawn on the effect of self-control in eating behaviour.

6.10 Contributions and recommendations

The overall aim of this research was to systematically assess the role of self-control in determining an individual's eating behaviour. Specifically, the thesis discussed the role of self-control in influencing an individual's food choice, energy intake, portion size and energy density in different eating scenarios. In addition, the thesis investigated the possibility of a cognitive training paradigm moderating an individual's self-control. The research used both general trait self-control (*i.e.* Tangney's Brief Self-Control Scale) and domain-specific self-control (*i.e.* Food Self-Control Scale) measures. Eating behaviours were assessed in different eating scenarios (sweet snack, savoury snack, and main meal scenarios) using both food choice and quantity consumption measures.

The contributions that this thesis makes to theory and practice are multiple. The first major contribution is that the current thesis systematically tested the role of self-control in the context of food choice and food consumption. The thesis provides suggestions for effective assessments of self-control. For general trait self-control, both explicit and implicit self-control measure can predict food behavioural forced-choice responses to high-calorie foods. Explicit self-control measure (*i.e.* Tangney's Brief Self-Control Scale) was found as the most effective approach for predicting food choice, however, it did not directly influence on energy intake. Therefore, implicit measures offer an alternative for the assessment of self-control. For food-domain specific self-control, it was found that food self-control only had an effect on food energy density, but no effect on portion size. This contributes to current knowledge of food-domain specific self-control in regulating eating behaviour via the energy density of the food. The recommendation regarding capturing the individual difference in eating behaviour should apply a food-domain specific self-control measure (*i.e.* Food Self-Control Scale), which facilitates greater insights into various eating scenarios.

The second major contribution is that the thesis assessed the role of self-control in different eating scenarios (sweet snack, savoury snack, and main meal scenarios) using both food choice settings and quantity consumption measures. The thesis provides suggestions for effective measures of eating behaviours in self-control related research. It is recommended that eating behaviour measure (food consumption and food choice) applied to signify self-control conflicts ought to comprise one unhealthy food option that the participants perceived to be desirable (instantaneous satisfaction), and one healthy food option that the participants find comparatively less appealing (weight management). As such, high and low energy density food settings enhance the possibility of triggering self-control conflict.

The third contribution is that this research adds important insights into the top-down and bottom-up processes in food choice and energy intake. The moderating role of self-control was found in both sweet food and savoury snacks, but not in the main meal scenario. As such, this research usefully contributes to current knowledge of top-down and bottom-up processes in food choice and energy intake across different food types. Recommendations regarding the food types applied in self-control related research may target both sweet and savoury snacks rather than the main meal scenario.

The fourth major contribution of this work is that the thesis developed a cognitive training paradigm for low self-control individuals and tested its effectiveness on influencing both portion size and energy density. It provided positive evidence for the tested cognitive training paradigm on affecting eating behaviour. Future research could apply a targeted measure in assessing long-term effect, in order to attain a better understanding of individual suitability for an intervention to decrease unhealthy eating.

6.11 Conclusions

Overall, this doctoral research assessed the role of self-control in determining an individual's eating behaviour in different eating scenarios. Findings from this thesis suggest that self-control, as a top-down self-control trait, is associated with the choices of food energy density, it however does not directly affect food portion size and energy intake. The moderating role of self-control on food choice and energy intake differs across eating scenarios (found in both sweet and savoury snack, but not in main meal scenario). Overall, this research provides important and novel insights into the role of self-control in regulating eating behaviour through the energy density of the food. It indicates the possible direction of an intervention strategy for those low self-control individuals, since the targeted cognitive training paradigm is effective to affect eating behaviour.

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Appendices:

Appendix 1: Tangney's Brief Self-control Scale

Using the 1 to 5 scale below, please indicate how much each of the following statements reflects how you typically are:

Not at all **Very much**

1 **2** **3** **4** **5**

	Statements	***Score***
1.	I am good at resisting temptation.	
2.	I have a hard time breaking a bad habit.	
3.	I am lazy.	
4.	I say inappropriate things.	
5.	I do certain things that are bad for me if they are fun.	
6.	I refuse things that are bad for me.	
7.	I wish I had more self-discipline.	
8.	People would say that I have an iron self-discipline.	
9.	Pleasure and fun sometimes keep me from getting work done.	
10.	I have trouble concentrating.	
11.	I am able to work effectively toward long-term goals.	
12.	Sometimes I can't stop myself from doing something, even if I know it is wrong.	
13.	I often act without thinking through all the alternatives.	

(Tangney et al., 2004)

Appendix 2: Food self-control scale

Using the 1 to 5 scale below, please indicate how much each of the following statements reflects how you typically are:

Not at all **Very much**

1 2 3 4 5

	Statements	***Score***
1.	I am good at resisting tempting food.	
2.	I have a hard time breaking bad eating habits.	
3.	I eat inappropriate things.	
4.	I eat certain things that are bad for my health if they are delicious.	
5.	I refuse to overindulge on foods that are bad for me.	
6.	People would say that I have an iron self-discipline with my eating.	
7.	I am able to work effectively toward long-term health goals.	
8.	Sometimes I can't stop myself from eating something, even if I know it is bad for me.	
9.	I often eat without thinking through the health consequences.	
10.	I wish I had more self-discipline in food consumption	

(Haws et al., 2016b)

Appendix 3: The Dutch Eating Behaviour Questionnaire (DEBQ)

Using the 1 to 5 scale below, please indicate how much each of the following statements reflects how you typically are:

Never	Seldom	Sometimes	Often	Very often
1	**2**	**3**	**4**	**5**

	Statements	***Score***
1.	If you have put on weight, do you eat less than you usually do?	
2.	Do you try to eat less at mealtimes than you would like to eat?	
3.	How often do you refuse food or drink offered because you are concerned about your weight?	
4.	Do you watch exactly what you eat?	
5.	Do you deliberately eat foods that are slimming?	
6.	When you have eaten too much, do you eat less than usual the following days?	
7.	Do you deliberately eat less in order not to become heavier?	
8.	How often do you try not to eat between meals because you are watching your weight?	
9.	How often in the evening do you try not to eat because you are watching your weight?	
10.	Do you take into account your weight with what you eat?	
11.	Do you have the desire to eat when you are irritated?	
12.	Do you have a desire to eat when you have nothing to do?	
13.	Do you have a desire to eat when you are depressed or discouraged?	
14.	Do you have a desire to eat when you are feeling lonely?	
15.	Do you have a desire to eat when somebody lets you down?	

16.	Do you have a desire to eat when you are cross?	
17.	Do you have a desire to eat when you are approaching something unpleasant to happen?	
18.	Do you get the desire to eat when you are anxious, worried or tense?	
19.	Do you have a desire to eat when things are going against you or when things have gone wrong?	
20.	Do you have a desire to eat when you are frightened?	
21.	Do you have a desire to eat when you are disappointed?	
22.	Do you have a desire to eat when you are emotionally upset?	
23.	Do you have a desire to eat when you are bored or restless?	
24.	If food tastes good to you, do you eat more than usual?	
25.	If food smells and looks good, do you cat more than usual?	
26.	If you see or smell something delicious, do you have a desire to eat it?	
27.	If you have something delicious to eat, do you eat it straight away?	
28.	If you walk past the baker, do you have the desire to buy something delicious?	
29.	If you walk past a snack bar or a cafe, do you have the desire to buy something delicious?	
30.	If you see others eating, do you also have the desire to eat?	
31.	Can you resist eating delicious foods?	
32.	Do you eat more than usual, when you see others eating?	
33.	When preparing a meal, are you inclined to eat something?	

(Van Strien et al., 1986a)

Appendix 4: The stimuli used in Chapter 5

High energy density food **Low energy density food**

ED: 336.39 Kcal/100g
1French fries

ED: 43.13 Kcal/100g
1 Garden salad

ED: 304.87 Kcal/100g
2 Mac cheese

ED: 30.8 Kcal/100g
2 Steamed broccolis

ED: 317.15 Kcal/100g
3 Kumara wedges

ED: 32.97 Kcal/100g
3 Carrots

ED: 243.41 Kcal/100g
4 Pasta

ED: 97.47 Kcal/100g
4 Couscous

Household items

1 Tong

2 Screwdriver

3 Towel

4 Peeler

Office items

1 Stapler

2 Marker pen

3 Paper clips

4 Foldback clips

Appendix 5: Information Sheet 1 for Participants

[Reference Number: *as allocated upon approval by the Human Ethics Committee*]
[*Date*]

The difference in food preference across different eating scenarios

INFORMATION SHEET FOR PARTICIPANTS

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate, we thank you. If you decide not to take part in, there will be no disadvantage to you, and we thank you for considering our request.

What is the Aim of the Project?

The research aims of the current study are to investigate the difference in food preference across the different eating scenario.

What Type of Participants is being sought?

We are looking for 66 participants for this study, the criteria for the participants are:

- Female;
- NZ European or those who have resided in New Zealand for at least 10 years;
- Aged between 18 and 50;
- Healthy;
- No known food allergies (food to be taken in this study are porridge, milk, potato chips, ice cream and pasta. These foods may include gluten, soy, meat, wheat, dairy, and eggs);
- Not vegetarian/vegan;
- Not involved in a diet programme to gain weight or reduce weight.

What will Participants be Asked to Do?

You will be asked to complete an online questionnaire. Prior to the session, you will be asked to refrain from eating 2 hours prior to the study. In case you had consumed food within the last 2 hours, you could undertake the questionnaire later in your own time. At the start of the questionnaire, you will be asked to complete the consent form before completing the questionnaire.

First, you will be asked how hungry you are. Then you will be presented with porridge with milk for the morning session. Then, you will be asked to come back in 2 hours for the later session. Then, you will be asked how hungry you again, you will be asked to evaluate the food preference across different eating scenarios. In addition, you will be asked about your eating habits and demographic information.

At the end of the study, participants will be entered into a draw competition with a chance to win a $100 New World Voucher.

Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind, although in this case you are not eligible to enter the draw competition.

What Data or Information will be Collected and What Use will be Made of it?

Your response to the questions and the tasks given in this study will be recorded for statistical analysis. Your personal information (name and contact details) will be collected only for this study's purpose.

The raw data collected will only accessible to the student researcher and the supervisors who conduct this study. This data will not be disclosed to any third party unless it is required by law or university's policy. The analyzed data will not contain any personal information (name and contact details). Any personal information held on the participants (such as contact details) will be destroyed at the completion of the research even though the data derived from the research will, in most cases, be kept for much longer or possibly indefinitely.

The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve your anonymity. The analyzed data may be used for further research, journal article, book, and presentation. Data obtained as a result of the research will be retained for at least 5 years in secure storage.

If you have any concerns about the ethical conduct of the research, you may contact the Committee through the Human Ethics Committee Administrator (phone 03479 8256). Any issue you raise will be treated with confidence and investigated, and you will be informed of the outcome.

Can Participants Change their Mind and Withdraw from the Project?

You may withdraw from participation in the project at any time during the study session and without any disadvantage to yourself of any kind, although in this case you are not eligible to participate in the draw competition.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:-

Justin Geng	and	*Dr. Mei Peng*
Department of Food Science		Department of Food Science
Phone Number: 0210764674		Telephone Number: 03 479 4052
Email: justin.geng@postgrad.otago.ac.nz		Email: mei.peng@otago.ac.nz

This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research, you may contact the Committee through the Human Ethics Committee Administrator (ph +643 479 8256 or email gary.witte@otago.ac.nz). Any issues you raise will be treated in confidence and investigated, and you will be informed of the outcome.

Appendix 6: Consent form 1

[Reference Number *as allocated upon approval by the Human Ethics Committee*]
[Date]

The difference in food preference across different eating scenarios

CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:-

- My participation in the project is entirely voluntary;
- I am free to withdraw from the project at any time without any disadvantage;
- I will need to attend 3 study sessions;
- Personal identifying information [name and contact details] will be destroyed at the conclusion of the project, but any raw data on which the results of the project depend will be retained in secure storage for at least five years;
- I will need to refrain from eating 2 hours prior to the sessions and I will consume food that contains meat, wheat, dairy, and eggs;
- I will be entered into a draw competition with a chance to win $100 New World voucher unless I decided to withdraw from the study;

The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve my anonymity.

I agree to take part in this project.

....

(Signature of participant) (Date)

....

(Printed Name)

…………………………………………………..

Name of person taking consent

This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research, you may contact the Committee through the Human Ethics Committee Administrator (ph +643 479 8256 or email gary.witte@otago.ac.nz). Any issues you raise will be treated in confidence and investigated, and you will be informed of the outcome.

Appendix 7: Information Sheet 2 for Participants

[Reference Number: *as allocated upon approval by the Human Ethics Committee*]
[*Date*]

Effects of self-control on energy intake across different eating scenarios

INFORMATION SHEET FOR PARTICIPANTS

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate, we thank you. If you decide not to take part in, there will be no disadvantage to you, and we thank you for considering our request.

What is the Aim of the Project?

This study aims to investigate the effects of self-control on energy intake across different eating scenarios.

What Type of Participants is being sought?

We are looking for 66 participants for this study, the criteria for the participants are:

- Female;
- NZ European or those who have resided in New Zealand for at least 10 years;
- Aged between 18 and 50;
- Healthy;
- No known food allergies (food to be taken in this study are porridge, milk, potato chips, ice cream and pasta. These foods may include gluten, soy, meat, wheat, dairy, and eggs);
- Not vegetarian/vegan;
- Not involved in a diet programme to gain weight or reduce weight.

What will Participants be Asked to Do?

You will be asked to complete an online questionnaire. Prior to the session, you will be asked to refrain from eating 2 hours prior to the study. In case you had consumed food within the last 2 hours, you could undertake the questionnaire later in your own time. At the start of the questionnaire, you will be asked to complete the consent form before completing the questionnaire.

First, you will be asked how hungry you are. Then you will be presented with porridge with milk for the morning session. Then, you will be asked to come back in 2 hours for the later session. Then, you will be asked how hungry you again, you will be presented with different types of food. You will be asked to consume food with a movie and how full you are. In addition, you will be asked about your eating habits and demographic information.

At the end of the study, participants will be entered into a draw competition with a chance to win a $100 New World Voucher.

Please be aware that you may decide not to take part in the project without any disadvantage to yourself of any kind, although in this case you are not eligible to enter the draw competition.

What Data or Information will be Collected and What Use will be Made of it?

Your response to the questions and the tasks given in this study will be recorded for statistical analysis. Your personal information (name and contact details) will be collected only for this study's purpose.

The raw data collected will only accessible to the student researcher and the supervisors who conduct this study. This data will not be disclosed to any third party unless it is required by law or university’s policy. The analyzed data will not contain any personal information (name and contact details). Any personal information held on the participants (such as contact details) will be destroyed at the completion of the research even though the data derived from the research will, in most cases, be kept for much longer or possibly indefinitely.

The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve your anonymity. The analyzed data may be used for further research, journal article, book, and presentation. Data obtained as a result of the research will be retained for at least 5 years in secure storage.

If you have any concerns about the ethical conduct of the research, you may contact the Committee through the Human Ethics Committee Administrator (phone 03479 8256). Any issue you raise will be treated with confidence and investigated, and you will be informed of the outcome.

Can Participants Change their Mind and Withdraw from the Project?

You may withdraw from participation in the project at any time during the study session and without any disadvantage to yourself of any kind, although in this case you are not eligible to participate in the draw competition.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:-

Justin Geng and *Dr. Mei Peng*

Justin Geng
Department of Food Science
Phone Number: 0210764674
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Dr. Mei Peng
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This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research, you may contact the Committee through the Human Ethics Committee Administrator (ph +643 479 8256 or email gary.witte@otago.ac.nz). Any issues you raise will be treated in confidence and investigated, and you will be informed of the outcome.

Appendix 8: Consent form 2

[Reference Number *as allocated upon approval by the Human Ethics Committee*]
[Date]

Effects of self-control on energy intake across different eating scenarios

CONSENT FORM FOR PARTICIPANTS

-I understand the data of food intake has been quantified and coded;

-I agree to this data can be used.

....
(Signature of participant) (Date)

-I would like to receive further information about this study. I will be asked to leave their contact details (e.g., email, phone, postal address). Upon completion of the study, I will receive a summary of the study findings;

I agree to receive further information about this study.

....
(Signature of participant) (Date)

....
(Printed Name)

…………………………………………………..
Name of person taking consent

This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research, you may contact the Committee through the Human Ethics Committee Administrator (ph +643 479 8256 or email gary.witte@otago.ac.nz). Any issues you raise will be treated in confidence and investigated, and you will be informed of the outcome.

Appendix 9: The first related publication co-authored during PhD

Cahayadi, J., **Geng, X.**, Mirosa, M., & Peng, M. (2019). Expectancy versus experience–Comparing Portion-Size-Effect during pre-meal planning and actual intake. ***Appetite*, *135***, 108-114.

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Expectancy versus experience – Comparing Portion-Size-Effect during pre-meal planning and actual intake

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Eating behaviour
Portion labelling

A B S T R A C T

Research on eating behaviour has confirmed that portion size can substantially influence intake, a phenomenon known as the Portion-Size-Effect (PSE). Despite extensive research interest, there is limited understanding about the PSE on intended consumption (often measured by Expected Intake). It also remains unclear whether the presentation of food cues (e.g., Word Descriptors; Food Images) can modulate PSE during pre-meal planning. The current study addressed these questions by comparing PSE on intended versus actual consumption, with 62 participants based on a within-subject design. Participants firstly rated Expected Intake for a pasta dish of three sizes (400, 600, and 800 g), with each size presented in three different formats of food cues. The participants' actual pasta intake with the three portion sizes was tested in three *ad libitum* sessions over 7 weeks. The results suggested that Expected Intake increases as portion size becomes larger, following a nearly linear relationship. In comparison, the Actual Intake had a smaller increment after the presented portion size exceeded the 'appropriate' range. Relating to these results, the pre-meal PSE was found to be comparable to the actual PSE with moderate portion sizes (i.e., 600 g-400 g), but significantly stronger than the actual effect with large portion sizes. Overall, our data support the hypothesis that portion size can have a stronger influence on meal planning than actual food intake, and show that the format of food cues has considerable influence on Expected Intake. Studies of pre-meal planning should carefully consider the role of portion sizes and food cues on Expected Intake.

1. Introduction

Obesity is a global problem. Although the aetiology of obesity relates to diverse factors, one of the apparent drivers lies in the current food environment, which promotes over-consumption of high-energy but nutrient-poor food. For instance, food portion size has been increasing since the 1970s (Duffey & Popkin, 2011; Young & Nestle, 2002), which directly impacts on energy intake and ultimately elevates body weight (Rolls, Roe, & Meengs, 2007). This phenomenon has been demonstrated in empirical studies of eating behaviour, whereby portion size substantially influences on energy intake, known as the Portion-Size-Effect (PSE) (Ello-Martin, Ledikwe, & Rolls, 2005; Rolls et al., 2007; Rolls, Roe, Kral, Meengs, & Wall, 2004).

The PSE has been well-studied across food types, populations and eating scenarios (Zlatevska, Dubelaar, & Holden, 2014), although the mechanisms underlying this effect remain unclear (Benton, 2015; Herman, Polivy, Pliner, & Vartanian, 2015; Steenhuis & Poelman, 2017). In the past decade, several proposals have been put forward in an attempt to unravel the mechanisms underlying PSE on food intake (Steenhuis & Poelman, 2017). One of the commonly-accepted hypotheses is related to the perception of "appropriate" or "normal" portion sizes (Haynes et al., 2019). Marchiori, Papies, and Klein (2014) explained this view with the anchoring and adjustment theory, whereby perceived portion size acts as a reference point (i.e., the "anchor") for steering food intake. Conceivably, large serving sizes distort an individual's perceived portion size, which can then override the adjustment process and lead to altered energy intake.

To date, much of PSE research has focused on energy intake with an *ad libitum* design (Ello-Martin et al., 2005; Rolls et al., 2004, 2007). Recently, there is increasing recognition of the role of pre-meal planning in determining food and energy intake. In most eating scenarios, an individual plans their food portion (measured by Expected Intake) prior to the actual intake, and then consumes the meal in its entirety (Fay et al., 2011; Wilkinson et al., 2012), particularly in Western cultures (Peng et al., 2017). Emerging evidence suggests that portion size is a major factor influencing Expected Intake (Marchiori et al., 2014; Robinson et al., 2016; Robinson, te Raa, & Hardman, 2015). For instance, Robinson et al. (2015) employed a between-subject design to assess discrepancies between Expected Intake (based on Food Images) and actual intake of ice cream in large and small sizes. Their results

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found that large portion size led to higher Expected Intake, implying the presence of PSE in pre-meal planning, herein termed as the "pre-meal PSE". In the literature, comparisons between Expected Intake and Actual Intake often suggest inconsistencies between these parameters (Fisher, 2007; Zuraikat, Roe, Privitera, & Rolls, 2016). Conceivably, such discrepancies can be attributed to the different mechanisms responsible for pre-meal planning and actual consumption. Food consumption is thought to be governed by a combination of internal and external factors – the former referring to physiological or biological responses, such as secretion of hormones (Benelam, 2009; Woods, Benoit, Clegg, & Seeley, 2004), and the latter referring to perceptual factors, such as portion size (Brunstrom, Collingwood, & Rogers, 2010; Marchiori & Papies, 2014; Oldham-Cooper, Wilkinson, Hardman, Rogers, & Brunstrom, 2017; Peng, 2017). By contrast, although pre-meal planning involves evoking episodic memory of previous eating experiences (Brunstrom et al., 2012), this planning process predominantly relies on external factors (Herman & Polivy, 2008). Drawing on these recent studies, we hypothesise that portion size, as an external factor, exerts a stronger influence on pre-meal planning than on actual consumption. Given the increasing interest of PSE on perceived portion sizes, it is crucial to test this hypothesis empirically.

Portion information is delivered by food cues, which have been shown to strongly influence pre-meal planning (Wadhera & Capaldi-Phillips, 2014), with augmented food cues directly resulting in altered energy intake (e.g., Marchiori, Corneille, & Klein, 2012; McClain et al., 2013; Peng, 2017; Robinson et al., 2016). While using Word Descriptors (e.g., "large", "400 g") is still the primary mechanism of conveying portion size, there is an increasing trend to utilise other visual formats (e.g., Food Images or 3D Models) for assisting people with portion estimates. These different formats of food cues are expected to influence people's portion perception, and correspondingly their intended consumption. Indeed, Frobisher and Maxwell (2003) found that judgements of Expected Intake based on food images were more indicative of actual intake than information from Word Descriptors. Based on these findings, we hypothesise that specific food cues may be more susceptible to perceptual biases for judging portion sizes than others, causing larger PSE during pre-meal planning. To test this prediction, the present study incorporates three different visual formats when assessing the effect of portion size on intended consumption.

The current study aims to systematically evaluate the effects of portion sizes on Expected Intake during pre-meal planning and actual consumption, using a within-subject design. In particular, the study addresses whether PSE is more pronounced for intended versus actual consumption. Findings from this study will generate practical insights into effective uses of food cues for portion regulation, and will contribute to the understanding of mechanisms underpinning PSE.

2. Methods

2.1. Participants

Eighty-six participants were initially recruited, of whom 73 completed this study. The inclusion criteria were healthy individuals between the age of 18 and 60 years, consumers of pasta (i.e., consume at least once per month), with no food allergies or restrictions, and not under any dietary program to gain or lose weight. Participants were also asked to complete the Dutch Eating Behaviour Questionnaire (DEBQ) as a supplementary task.

A screening process was performed to check the quality of the questionnaire data at the end of the study. Eleven participants were identified as habitual respondents as they gave 100 for all of the questionnaire items, and data from these subjects were excluded from subsequent analyses. Therefore, the final dataset comprised response data obtained from 62 participants (29 females and 33 males; 42 healthy weight (BMI within 18.5-24.9 kgm^{-2}) and 20 overweight (BMI above 25 kgm^{-2})). All participants gave written consent prior to the commencement of the study. This research was approved by the University of Otago Human Ethics Committee (17/139).

2.2. Samples

The present study used pasta bolognese as the testing food sample, given the broad popularity of this dish among the testing population. All samples used in the current study were made following a pre-determined recipe in a standard food-grade laboratory. For the first session, 9 types of Food Cues were constructed, including Word Descriptors, Food Images and 3D Models for pasta bolognese in three different sizes (i.e., 400 g, 600 g, and 800 g). The Word Descriptor included the name of the dish and specification of the weight of the food (in grams). In order to develop Food Cues based on Food Images and 3D Models, we cooked and prepared the pasta dish in three sizes (400 g, 600 g and 800 g; ± 0.9 g), and placed them on plates with a diameter of 25 cm. Care was taken with the placement of food on the plate. Each Food Image was constructed by photographing the dish from the top view under constant lighting condition on a black background. Each 3D Model was prepared by taking a series of photos from the top, angular and front view for every 10^0 rotation in the y-axis. The 3D Models were post-processed with Agisoft professional (version 1.3.4.5067, Agisoft LLC, Russia) and Blender (version 2.78, Blender Foundation, Netherlands). In order to provide a realistic scale of the dish in the visual food cues, a standard unlabelled 330 ml can, had been added next to the pasta dish as a point of reference. All of these 9 Food Cues were incorporated into questionnaires and uploaded onto Qualtrics (2016, USA). The 3D Models were presented in Qualtrics as an embedded link via an online 3D model platforms (www.sketchfab.com).

For the remaining three sessions, the same pasta bolognese dish was prepared for each participant. The cooking took place 60-min prior to the start of each session. The food was served 5–7 min after being cooked, at approximately 60 °C. Food samples were weighed immediately before and after consumption (± 0.9 g).

2.3. Procedures

Each participant attended four experimental sessions after a 3 + hour fasting. Fig. 1 provides a schematic outline of the experimental procedure. Data collection for the present study took place in a standard sensory laboratory, with each participant seated in an individual booth with controlled lighting. Participants were informed that the purpose of the study was to examine the effect of portion labelling on eating behaviour, and minimal additional information was provided. The study protocol conformed to Robinson, Bevelander, Field, and Jones (2018) as closely as possible.

At the start of each session, participants were asked to rate their hunger level on a 100-point Visual Analogue Scale (VAS). In Session 1, the participants were presented with each of the 9 Food Cues in a randomised order and asked to indicate "How much would you eat from this plate to be full?" on a 100-point VAS. Subsequently, these participants attended three *ad libitum* sessions in a fasting-state, at 2 week intervals. At the beginning of each session, participants were asked to rate their liking for the pasta dish (with one spoonful) on a 100-point VAS. They were then asked to consume the presented pasta dish *ad libitum*. The participants were specifically instructed not to lift the pasta dish while consuming the food. They were given a controlled amount of water during the consumption (125 ml). The presentation order of different portion sizes was counterbalanced across all sessions and participants. Participants were also asked to refrain from using a mobile phone, talking and sharing their food with other participants during the session.

At the end of the study, participants' height and weight were measured (without shoes), following the anthropometric standardisation reference manual (Lohman, Roche, & Martorell, 1988). Measurements for each participant were undertaken twice; if the difference between

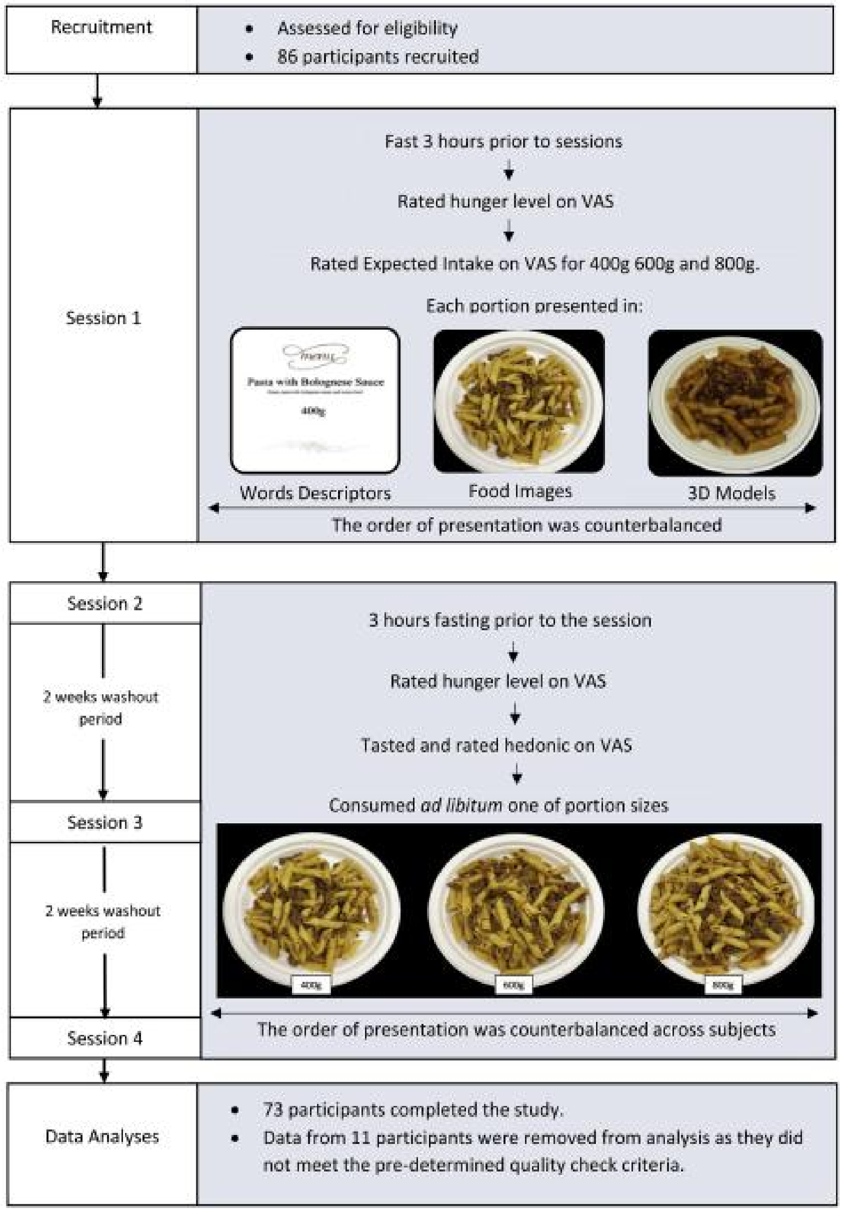

Fig. 1. Schematic representation of the experimental procedure.

the two measurements ≥1 cm or 0.1 kg, a third measurement was conducted. The mean value of the two closest measurements was used in the analysis. At the completion of the final experiment, each subject was asked to confirm that they were unaware of the purpose of the study; full study information was subsequently disclosed to each participant.

2.4. Data analyses

The first part of the analysis aimed to test the effects of portion size on energy intake for both intended and actual consumption. For actual consumption, the energy intake was calculated as the product of food intake (weight) and caloric value (Foodworks; version 9, Xyris software, Australia). With intended consumption, the participants' response on VAS was first translated into a weight measure (grams) and then converted into an energy measure (kcal), following the protocol described in Robinson et al. (2015). A mixed-effects linear model was employed to assess differences in energy intake in different testing conditions. Portion Size (400 g, 600 g, and 800 g) and experimental conditions (Word Descriptors, Food Images, 3D Models, and Actual Intake) were included as fixed factors and 'participant ID' was defined as a random factor.

In this paper, the pre-meal PSE and actual PSE were quantified as the caloric difference between two adjacent portion sizes. Previously, PSE is often measured by calorie changes across portion sizes in percentage (*e.g.*, Robinson et al., 2015). The present study used a within-subject design, providing an opportunity to run quantitative analyses on the actual PSE measures. In addition, Paired-Sample t-tests were used to test individual differences between pre-meal and actual PSE, for each of the Food Cues. Furthermore, Pearson's correlation between pre-meal PSE and actual PSE for each food cue was also calculated. All analyses were conducted with SPSS (version 25, IBM, USA). Significant statistical results were indicated by $p < 0.05$ (*Bonferroni*-corrected *p*-value). The full dataset has been made available on the Open Science Framework at https://osf.io/wx8y5.

3. Results

3.1. Participant characteristics

Participants had a mean age of 23.7 years (SD = 7.5), a mean BMI of 23.4 kgm^{-2} (SD = 3.0), and a mean DEBQ-restrained score of 3.5 (SD = 0.5). Each participant was also asked to provide hunger ratings at the beginning of each experimental session, and hedonic ratings in *ad libitum* sessions. These statistics are included in Table 1.

A series of univariates analyses were performed to detect any significant difference, due to gender or BMI in the Expected Intake and Actual Intake. Significant differences with regard to gender were observed for all Expected and the Actual Intake ($p < 0.05$), with females reporting and consuming less food/energy. With BMI, differences were observed for Expected Intake based on Food Images, with the higher BMI group reporting higher intake. Given these preliminary insights, all subsequent analyses were based on repeated-measures design. Notably, results from repeated-measures ANOVA suggested that hedonic and hunger ratings did not vary significantly across the experimental sessions. Descriptive statistics are included in Table 1.

3.2. Effects of food cues and portion sizes on expected intake

A mixed-effects linear model was performed on measures of energy intake to assess effects due to experimental conditions (i.e., 3 Food Cues and Actual Intake) and Portion Sizes. We detected a significant interaction between these two testing factors ($F(6,62) = 9.08$, $p < 0.001$; Fig. 2). Post-hoc tests with *Bonferroni* corrections indicated that, for the portion size of 400 g and 600 g, the Actual Intake was comparable to the Expected Intake based on Food Images and 3D Models, all of which were significantly higher than the expected measure based on Word Descriptors ($p < 0.05$). However, at the portion size of 800 g, the Actual Intake was comparable to the Expected Intake based on Word Descriptors but significantly lower than the measures associated with Food Images and 3D Models ($p < 0.05$).

Table 1
Descriptive statistics of the participants' characteristics (N = 62), and hedonic and hunger ratings (on a 100-point Visual Analogue Scale) across four sessions.

Study sessions	Mean	SD
Hedonic – Session 1	n/a[a]	n/a[a]
Hedonic – Session 2	79.7	13.7
Hedonic – Session 3	80.2	12.6
Hedonic – Session 4	82.2	13.0
Hunger – Session 1	72.0	16.4
Hunger – Session 2	75.5	16.2
Hunger – Session 3	77.3	15.4
Hunger – Session 4	76.7	17.9

Overall, portion size was found to have a significant main effect on the estimated and actual energy intake ($F(2,62) = 285.69$, $p < 0.001$). Averaged energy intake (across both estimated and actual measures) associated with the portion size of 800 g (M = 900.9, SE = 21.5) was significantly higher than the portion size of the 600 g (M = 761.7, SE = 14.0) and 400 g (M = 544.7, SE = 6.9). Experimental conditions also had a significant main effect on the overall energy intake ($F(3,62) = 19.43$, $p < 0.001$). Specifically, energy intake estimated with Food Images (M = 786.7, SE = 14.0) was significantly higher than all other experimental conditions ($p < 0.05$). Notably, Actual Intake (732.4, SE = 14.4) was comparable to Expected Intake measured by 3D Models (M = 745.3, SE = 16.0) and Word Descriptors (M = 687.5, SE = 22.2).

A series of paired sample t-tests were applied to assess differences between estimated and actual PSE (Table 2). Across the Food Cues, results from the t-tests consistently showed no difference between the estimated and actual PSE when the portion size increased from 400 g to 600 g, but significant differences between these two PSE measures for 800 g-600 g comparisons with Food Images and 3D Models (Cohen's d was 0.87 and 0.71, respectively). However, Pearson's correlations between the estimated and actual PSE produced significant results for PSE between 600 g and 400 g, but not for 800 g-600 g comparisons (Fig. 3).

4. Discussion

The results showed that large portion size led to higher energy intake for both pre-meal planning and food consumption, consistent with recent findings in general (Marchiori et al., 2014; Robinson et al., 2015, 2016; Zuraikat et al., 2016). Specifically, the present study indicated that the Expected Intake increased linearly with portion size, whereas the Actual Intake had a smaller increment after the presented portion size exceeded the 'appropriate' range. Related to these results, pre-meal PSE was found to be comparable to actual PSE for moderate portion sizes (i.e., 600 g-400 g), but significantly stronger than the actual effect for large portion sizes. These novel observations lend support to our hypothesis that portion size has a stronger influence on meal planning than food consumption – but only when the portion size exceeds the "appropriate" range.

Both previous studies and the current analysis indicate that actual food intake exhibits a non-linear relationship with portion size. Specifically, after exceeding a certain portion size, an individual's consumption approaches an asymptote (Roe, Kling, & Rolls, 2016; Zlatevska et al., 2014). Although no previous studies have assessed the relationship between Expected Intake and portion sizes, Robinson et al. (2015) assumed that Expected Intake would follow a similar non-linear relationship against portion size, on the basis that individuals are adept at estimating expected satiation and adjusting Expected Intake accordingly (Brunstrom et al., 2010; Brunstrom & Rogers, 2009). Contrary to Robinson et al.'s assumption, the present study observed a near linear relationship, with Expected Intake increasing at a constant rate across the three portion sizes. This finding apparently reflects the diminished effects of Expected Satiation on Expected Intake as portion sizes increase, as suggested in a recent study by Brunstrom et al. (2016).

Evidently, discrepancies between pre-meal and actual PSE vary across portion sizes. The pre-meal PSE was comparable to the actual PSE for small portions (*i.e.*, 600 g-400 g), corroborating Robinson et al. (2015). However, with large portion sizes (*i.e.*, 800 g-600 g), the Expected Intake led to higher-than-actual PSE. This observation is consistent with the findings of Zuraikat et al. (2016), whereby individuals

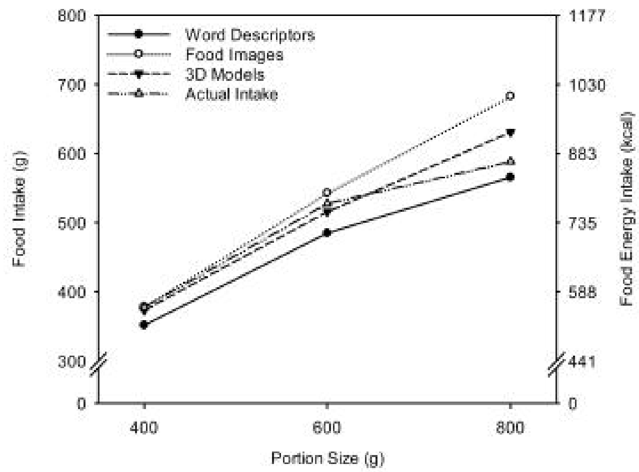

Fig. 2. Averaged food and energy intake for three portion sizes of pasta, along with measures of Expected Intake (in both grams and kcal) based on three different food portion cues.

constantly choose larger portion sizes, even when their actual intake stabilises. Moreover, pre-meal PSE was correlated to actual PSE only when portion sizes were within an "appropriate" range. These results highlight the interacting effects of internal and external drivers of portion estimation. Indeed, previous research has suggested that pre-meal portion estimation is prone to errors as it is primarily based on external factors (Pierre & Ordabayeva, 2009; Slawson & Eck, 1997). Here, we show that these judgement errors can be compensated by internal factors during meal intake. For instance, hunger level gradually declines during a meal (Morton, Cummings, Baskin, Barsh, & Schwartz, 2006; Yeomans, 2000), which leads to a faster termination of food intake and reduced PSE. Another important driver is palatability, which is typically high during pre-meal planning (leading to high Expected Intake) and reduced during food intake (leading to low consumption) (Rolls, Rolls, Rowe, & Sweeney, 1981).

Previously, researchers have highlighted the importance of providing portion size information or labelling to the general public for accurate portion judgements (Steenhuis & Poelman, 2017; Vermeer, Steenhuis, & Poelman, 2014). Critically, findings from the present study indicate that the format of food cues can substantially affect individuals' Expected Intake, corroborating the results of Frobisher and Maxwell (2003). Interestingly, our results indicate that different food cues did not significantly change the size of PSE during pre-meal planning, with Food Images and 3D Food Models leading to particularly exaggerated PSE for large portion sizes.

A possible caveat of the current study lies in its ecological validity, having been undertaken in a controlled laboratory setting. Individual eating behaviour has been shown to vary considerably across controlled versus real-life environments (Wang, Cakmak, & Peng, 2018). Given the minimal sensory distraction in the laboratory environment, participants might experience heightened attention towards food cues and tasks, which in turn might facilitate enhanced prediction of intake or portion size (Aydinoğlu & Krishna, 2011). An additional limitation relates to intake data (collected from the three *ad libitum* sessions) exhibiting a sequence effect. Despite our efforts in counterbalancing the testing orders across subjects, individual participants might potentially have altered behaviour across the testing sessions. Finally, future studies should trial alternative foods, such as snacks, given that previous research has shown that portion estimation can vary across food types (Almiron-Roig, Solis-Trapala, Dodd, & Jebb, 2013).

Overall, the present study shows that pre-meal PSE follows a different trajectory relative to actual PSE. While effects based on estimated measures were comparable to real effects involving small portions, they become exaggerated for large portions. Our data support the hypothesis that portion size can have a stronger influence on meal planning than food consumption, and show that the format of food cues can influence Expected Intake.

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Table 2
Results from t-tests assessing differences between the pre-meal PSE estimated by different food cues and the actual PSE (measured by kcal).

Food Cues	Portion levels							
	600 g-400 g (n = 62)				800 g-600 g (n = 62)			
	Pre-meal PSE		t-test		Pre-meal PSE		t-test	
	Mean	SE	t-statistics	p-value	Mean	SE	t-statistics	p-value
Word Descriptors	196.1	16.2	−1.39	0.171	118.9	13.7	1.14	0.258
Food Images	241.9	9.1	1.51	0.136	205.7	19.0	3.71	< 0.001
3D Models	209.4	11.0	−0.71	0.481	169.9	15.0	2.96	0.004

Note: PSE based on Actual Intake: 600-400 g – Mean = 220.6; SE = 14.4; 800-600 g – Mean = 89.14; SE = 23.9.

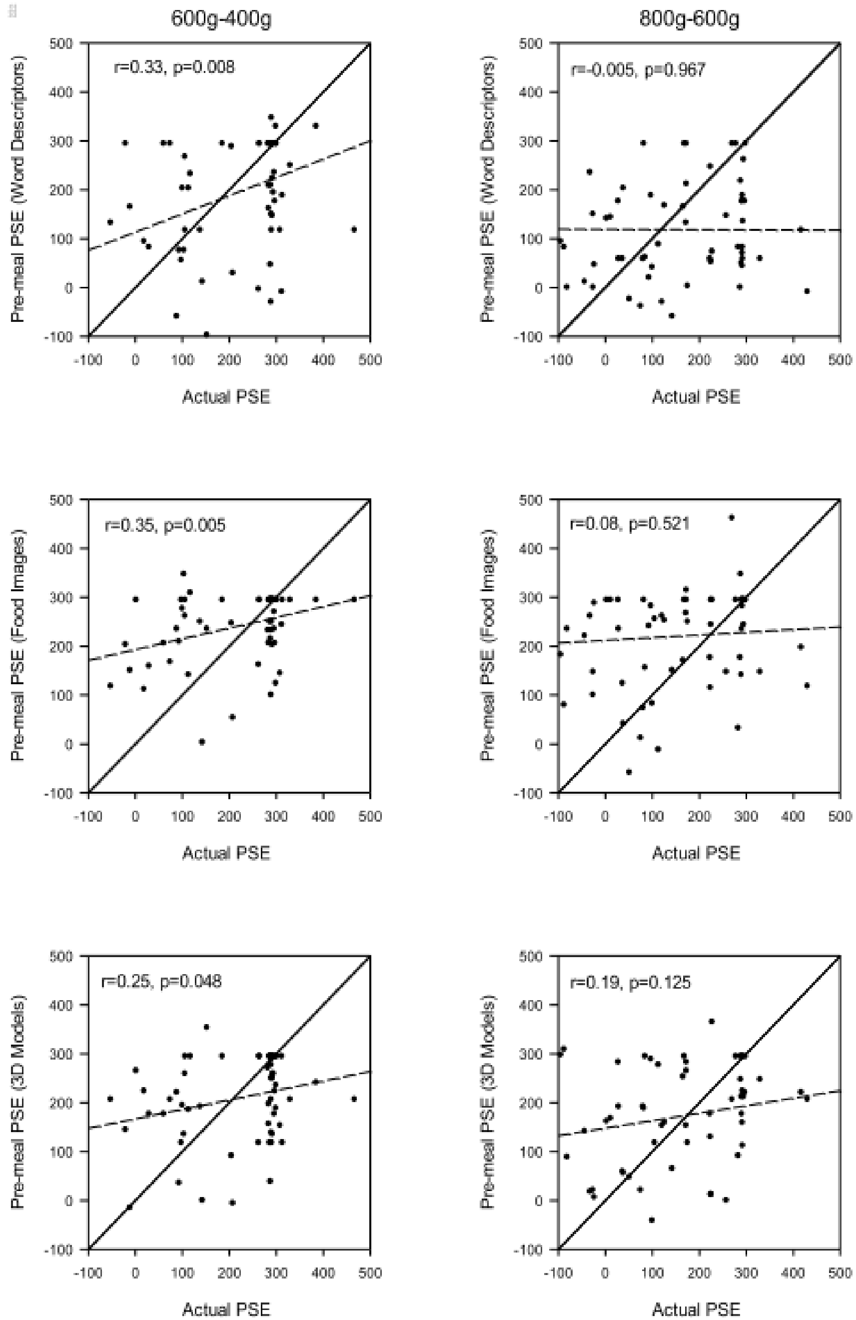

Fig. 3. Scatterplot with regression lines (dashed lines) illustrating relationships between the pre-meal and actual Portion-Size-Effect (PSE) for two separate portion levels (600 g-400 g; 800 g-600 g). Each panel represents a specific Food Cue.

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Appendix 10: The second related publication co-authored during PhD

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Mixed messages: Assessing interactions between portion-size and energy-density perceptions in different weight and sex groups

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ABSTRACT

Introduction: Food portion size (PS) and energy density (ED) are the two primary determinants of total energy intake. While emerging neuroscientific data indicate judgments of PS and ED involve distinct brain regions, it is not understood how these judgements interact with each other to influence an individual's energy consumption. The present study investigated these cognitive interactions against body-mass-index (BMI) and sex.

Methods: We tested 70 participants (including 34 overweight individuals) for cognitive biases when judging PS and ED, using the Garner task paradigm. Participants were asked to discriminate PS and ED, following pre-determined cognitive rules. Reaction time and correctness of their responses were recorded and analysed against the testing conditions across sexes and BMI groups.

Results: We detected a significant 3-way interaction between BMI, Task, and Condition ($F_{(3, 67)} = 4.1$, $p = 0.047$, $\eta^2 = 0.06$). Post-hoc tests suggested that, in the PS task, both weight groups experienced the Garner Interference effect introduced by variations of ED. That is, when making judgments concerning PS, participants were *unable* to ignore information relating to ED. Results from the ED task differed across weight groups, with only the overweight group being susceptible to the Garner Interference introduced by variations of PS. Additionally, both Sex and BMI were significant factors moderating reaction time when judging PS. Significantly longer reaction time was observed in female versus male comparisons, and for overweight versus healthy-weight participants ($p < 0.05$).

Conclusion: Overall, the results confirmed cognitive interactions involving PS and ED, although these interactions were asymmetric across BMI groups. These findings provide new insights into the cognitive processes underpinning individual dietary decision-making, and are potentially important for developing targeted intervention strategies for effective management of unhealthy eating behaviour.

1. Introduction

Obesity is an increasingly global problem (Abarca-Gómez et al., 2017; World Health Organisation, 2017). Although the causes of this condition comprise diverse factors, the contemporary food environment, with increasing portion size (PS) and energy density (ED), is a key contributor (Nielsen & Popkin, 2003; Young & Nestle, 2002). Indeed, research into human eating behaviour has shown strong evidence that both ED and PS of foods are important determinants of energy intake (Kral, Roe, & Rolls, 2004). Inaccurate judgements of PS or ED, in particular, can lead to substantial overconsumption of food and energy, especially in the current food environment with overwhelming exposure to food cues (Almiron-Roig, Solis-Trapala, Dodd, & Jebb, 2013; Rolls, Roe, & Meengs, 2007). The current study aims to investigate cognitive processes driving judgements of food PS and ED, and their links to individual body adiposity and sex.

With limited cognitive resources to process information, humans can only attend to selected information, resulting in attentional biases (Driver, 2001). An extensive body of literature has suggested that these attentional biases can possibly influence individual pre-meal planning (Doolan, Breslin, Hanna, & Gallagher, 2015; Nijs, Franken, & Muris, 2010; Nijs, Muris, Euser, & Franken, 2010). To date, there is still little empirical research that directly assesses attentional biases for judging PS and ED. However, many previous studies have attempted to understand the link between an individual's ability to estimate PS or ED, energy intake, and weight status. While a positive relationship has been reported between BMI and choice of portion size (Burger, Kern, & Coleman, 2007; Lewis et al., 2015), the link between BMI and energy

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density estimation remains controversial. Carels, Harper, and Konrad (2006) reported that participants with higher BMI showed greater inaccuracy in estimating energy density (in calorie value). These authors attributed their findings to possible attentional biases across individuals. Specifically, individuals who showed heightened attention to caloric information exhibited more restrictive eating behaviour. These findings have reinforced the importance of understanding attentional biases during dietary decision-making. More recently, Nijs and Franken (2012) recommended that studying attentional biases is of particular importance with regard to identifying cognitive factors preventing healthy food and portion choices, and determining causal relationships between weight problems and overeating.

Sex is another important personal factor that has been frequently reported to exert influences on judgments of ED or PS. While overestimation during pre-meal planning is prevalent in both males and females, recent studies have suggested substantial sex-related differences in food choice, in the balance of food components, and in the size of overestimation errors (Almiron-Roig et al., 2013; Arganini, Saba, Comitato, Virgili, & Turrini, 2012; Sharp, Sobal, & Wethington, 2019; Wardle et al., 2004). These differences were true after being corrected for differential energy requirements between males and females (Robinson, te Raa, & Hardman, 2015; Sharp et al., 2019). Such behavioural differences between sexes might also be attributable to attentional biases. Indeed, women are shown to be more attentive to caloric information relative to men, reflected by higher levels of brain activation when viewing high-calorie food pictures (Frank et al., 2010). These observations highlight the importance of understanding the contribution of sex in studying the attentional biases associated with dietary decision making.

Emerging neurological data in both children and adults suggest that judgments of PS and ED are accomplished via two separate cognitive processes, involving distinct brain regions (English et al., 2016; Toepel et al., 2015). Specifically, PS activates the lateral prefrontal cortex, indicating that processing of this information primarily involves cognitive control (Keller et al., 2018). By contrast, ED provokes multiple brain areas involved in sensory and reward processing, including insula, caudate, cingulate, and superior temporal and precentral gyri. Despite being associated with separated neural correlates, judgements of PS and ED occur simultaneously when an individual plans a meal in real life. Conceivably, the ED and PS information might interact during the process of meal-planning. Labbe, Rytz, Godinot, Ferrage, and Martin (2017) published some emerging data suggesting that portion selection can be largely influenced by individual perception of healthfulness (in relation to ED), pointing to the close interaction between PS and ED during meal-planning. The current study aims to specifically study such interaction between PS and ED.

We aim to employ an implicit cognitive method to test two hypotheses concerning attentional biases associated with estimation of PS and ED – (1) judgements of PS and ED interact with each other during pre-meal planning; (2) these cognitive processes can vary against BMI and sex of the participant. To achieve these objectives, we choose an existing cognitive task for testing attentional biases – the Garner two-choice speeded-classification task (i.e., the Garner task). The Garner task, similar to the Stroop task (Stroop, 1935), assesses selective attention for all classes of multidimensional objectives (see Algom & Fitousi, 2016, for a recent review; Garner, 1974, pp. 77–90). While the Stroop task has been widely used for investigating attentional biases with human eating behaviour (Johansson, Ghaderi, & Andersson, 2005), the Garner task is associated with a more specific application, which determines whether two stimulus dimensions interact with each other, and whether they are processed independently or in an integral manner. Although being a novel method for investigating human eating behaviour, the Garner task has been demonstrated useful in advancing understanding in several research areas, including emotion (Mama, Ben-Haim, & Algom, 2013), perception (Eidels, Townsend, & Algom, 2010), language (Lew, Chmiel, Jerger, Pomerantz, & Jerger, 1997), and memory (Melara & Nairne, 1991) research.

Overall, findings from this study will contribute to our understanding of cognitive processes during pre-meal planning, and illuminate inter-individual differences in dietary decision-making. We detect evidence for Garner Interference effects with PS judgements, regardless of BMI or sex. Additionally, BMI appears to moderate ED judgements, with the healthy-weight individuals not being affected by variations of PS.

2. Methods

2.1. Participants

Seventy participants were involved in the current study. While recruitment was open to the general community, most participants were students and staff members of the University of Otago, New Zealand. The participants were grouped into a healthy-weight group (N = 36; BMI between 18.5 and 24.9 kgm^{-2}) and an overweight group (N = 34; BMI above 25 kgm^{-2}), in accordance to the World Health Organisation BMI classification (World Health Organisation, 2019). The mean age of the participants was 21.5 (SD = 3.4), with a range of 18–34 years of age. The sample size was determined by a power analysis based on effect size previously reported in a food Stroop study (Braet & Crombez, 2003), with a 10% attrition rate considered. During the recruitment, candidates were asked to complete a pre-screening questionnaire to confirm their eligibility for participation in the experiment. Individuals who were undertaking a dieting program (either for weight gain or loss) were excluded from the study. The pre-screening questionnaire also asked for information about participant weight and height; these self-reported measures were used to assign individuals into the preliminary weight groups.

All participants were asked to abstain from any food or non-water beverage for at least 2 h prior to the experiment. At arrival, the participants were asked to report hunger on a 100-point Visual-Analogue-Scale (VAS). Upon completion of the experiment, the participants were asked to complete a brief demographic questionnaire (i.e., age, gender, and ethnicity), a Dutch Eating Behaviour Questionnaire (Restraint Eating Sub-category; van Strien, Frijters, Bergers, & Defares, 1986), and the Edinburgh Handedness Inventory (Oldfield, 1971). Finally, the participants' height and weight were measured in the laboratory, following the anthropometric standardisation reference manual (Lohman, Roche, & Martorell, 1988). Ethical approval for this study was granted by the Human Ethics Committee of the University of Otago (Reference number: 18/116). All participants gave a written consent and received a monetary reimbursement at the end of the study.

2.2. Stimuli

Food images used in the present study were customly made. We initially selected recipes of 20 dishes that were regarded familiar to local residents. Energy content of each dish was calculated using the Nutrition Panel Calculator (NPC) by Food Standards Australia New Zealand (FSANZ; Cunningham, Trevisan, & Milligan, 2004). The five dishes in the highest and lowest quartiles in caloric content, were used in the present study, and classified as high (> 700 kJ per 100g) and low (< 450 kJ per 100g) ED groups, respectively (see Table 1). All of the food items in the lower ED group are classified as low-energy dense (i.e., 251–628 kJ/100g) according to the World Cancer Research Fund (2007). Of the higher ED foods used, three are considered medium-energy (i.e., 628–941 kJ/100g), and two are high-energy (i.e., 941–1151 kJ/100g).

We then prepared these 10 selected dishes in a food-grade laboratory following the recipes. Each of these dishes was then arranged into a large and small portion size. The large portion size was placed on a plate with a diameter of 28 cm, and the small size was on a plate with a diameter of 20 cm. Previous research has shown that the food/plate

Table 1
List of dishes used in the present study with information of their energy density (kJ/100g).

	Food stimuli	Energy density (kJ/100g)
Low Energy Density	Garden Salad	249.5
	Shrimp Cocktail Salad	263.7
	Roast Pumpkin	346.0
	Poached Chicken Salad	368.3
	Corn and Tomato Salsa	437.6
High Energy Density	Hashbrown	726.0
	Deep Fried Spring Rolls	858.0
	All Day Breakfast	912.0
	Chicken Curry	986.0
	Deep Fried Wonton	1010.0

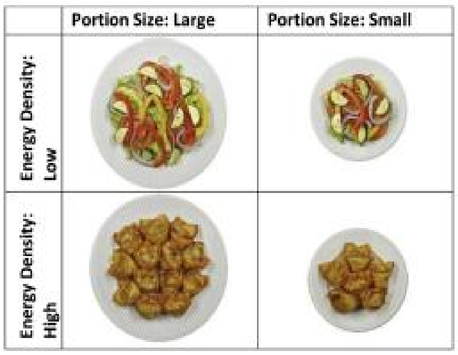

Fig. 1. Examples of stimuli used in the Garner task. The two variable dimensions are portion size and energy density.

space ratio can significantly alter an individual's perception of portion size (Peng, 2017; Sharp et al., 2019). To account for this, plates of different size were used to ensure that plate coverage was held constant across large and small portions (range of food to plate ratio: 0.41–0.47). A software ImageJ (1.52e; USA) was used to measure food to plate ratio. These dishes (10 dishes × 2 portion sizes) were photographed in a standardised object photobooth (Durst Phototechnik AG, Brixen, Italy). In the present study, the Garner task requires stimuli that vary in either PS or ED dimensions, with four possible organisations. The example of set images used in the Garner task are presented in Fig. 1.

2.3. Tasks

Each participant attended a 60-min session, which consisted of a Food Hedonic task and the Garner Speeded Classification Task (the Garner task). Both tasks were delivered by the INQUISIT software (Millisecond Software LLC, Seattle, USA) on a computer.

The Food Hedonic task was to ensure that the food images used in the experiment represent similar hedonic value to the participant. Specifically, the participant was presented with pictures of the 10 dishes (only one size was shown), and asked to respond to the question "how much do you like the presented dish?" on a 100-point VAS. The order of pictures was randomised for each participant. Based on the participant's responses, two dishes from the contrasting ED groups (high and low), which had the most similar hedonic scores (within 10-points), were identified. Altogether, four images – the large and small portion of the high and low calorie food – would be used to construct the Garner Task. This step was designed to ensure that the food images used in this the Garner tasks represented similar hedonic value to the participant, so their responses would not be biased by preference.

The Garner task includes two Baseline conditions, along with Correlation +, Correlation-, and Orthogonal conditions. In the Baseline condition, the relevant dimension is kept constant, while the irrelevant dimension varies in two levels in a randomised order. The Correlation + condition prescribes presentations of images with congruent characteristics, such as the small portion of the low energy dish or the large portion of the high energy dish. Conversely, the Correlation-condition only presents stimuli with incongruent dimensions. In the Orthogonal condition, all four pictures are shown in a randomised order. In all cases, the participants are asked to indicate the correct dimension of the stimulus as fast as possible. Typically, differences in the reaction time (RT) between the Orthogonal and the Baseline condition are referred to as the Garner Interference effect. Additionally, RT differences between the Correlation- and Correlation+ conditions are referred to as Correlation Differences, indicating effects of congruency on stimulus identifications.

In the Garner task, the participant was asked to perform a classification task based on only one stimulus dimension while ignoring the other. If the participant was able to ignore the irrelevant stimulus, then these two dimensions were considered to be independent. Alternatively, if the participant could not attend to one dimension without being affected by the other, then these stimulus dimensions were considered integral.

The present study employed a within-subject design to carry out the Garner task. Before the task, the participants were shown the two real plates used in the food images, so they have a mental representation of the size of the plates. Subsequently, each participant was required to perform two sub-tasks – energy density classification (ED task) and portion size classification (PS task), each contained 5 block as discussed in the Introduction (i.e., baseline 1 (B1), baseline 2 (B2), positive correlation (C+), negative correlation (C-) and orthogonal condition (O)). Each of the Baseline and Correlation conditions contains 80 trials, while the Orthogonal condition contains 160 trials. In total, there are 10 testing blocks with 960 testing trials. These 10 blocks were randomized and presented in a counterbalanced order across the participants.

In the Garner speeded classification task, a single food image was presented on each trial and participants had to classify the food item based on the values of one stimulus dimension, while disregarding the other dimension. For the ED task, the participants were required to indicate if the food depicted in the image belongs to the high or low ED category by pressing the specified key on the keyboard (either 'F' key or 'J' key). For the PS task, participants were required to indicate if the food image represents the big or small PS by pressing the specified key on the keyboard (either 'F' key or 'J' key). Fig. 2 illustrates events in a single trial of the Garner task.

2.4. Data analyses

Data from the Garner task were first submitted to an analysis of accuracy. A proportion correct (i.e., P(C); number of correct trials/total number of trials) was calculated for each individual for each block. For the reaction time (RT) analyses, data from incorrect trials and practice blocks were removed. In addition, trials with RT shorter than 150 ms or longer than 2000 ms were also removed because they represent anticipation and lack of attention. Two participants were excluded from subsequent analyses as their overall performance accuracy did not meet the pre-determined accuracy criterion (i.e., 80%). Reaction time (RT) of valid trials were then averaged across a single block for each individual. These RT data were then submitted to a mixed-model analysis of variance – 2 (BMI group: overweight vs. healthy-weight) × 2 (Sex: females vs. males) × 2 (Task: ED vs. PS) × 4 (Condition: Baseline (averaged across B1 and B2), C+, C-, and F) – with BMI groups as the between-subject variable and Task and Condition as the within-subject variable. The initial analyses included hunger level and food shape (i.e., discrete unit and amorphous) as covariates. The results indicated that neither of these variables had a significant effect on the dependent variable, and were thus discarded for subsequent analyses. All analyses were

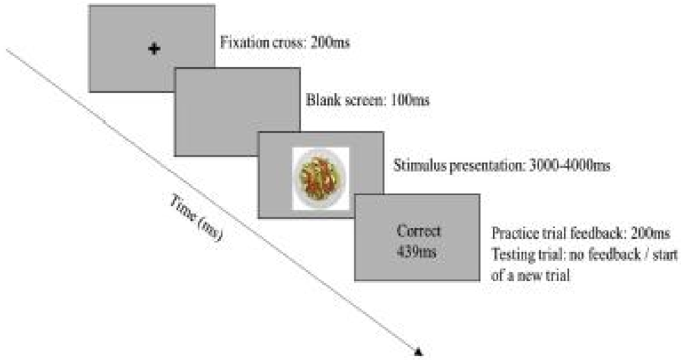

Fig. 2. Illustration of a single trial of the Garner Speeded Classification Task.

performed on SPSS (v25, IBM).

In addition, a separate analysis was conducted to assess significant values for Garner Interference (GI = Orthogonal – Baseline average) and Correlation Differences (CD = Correlation- – Correction+) on the individual level.

3. Results

Relevant demographic information of the participants is summarised and presented in Table 2. Three participants had been identified as left-handed, although their reaction time was not different from the rest of the participants. Based on self-reported major ethnicity, both healthy-weight and overweight groups had similar ethnicity ratios. While some differences were observed across these groups in terms of DEBQ-R score, these scores were not significantly different across the weight groups.

3.1. Accuracy

After removing data from two individual participants who had P(C) under 0.8, the overall accuracy across participants was high, with incorrect responses accounting for only 3.1% of overall data. A series of Wilcoxon Signed Rank tasks were performed to detect significant differences in P(C) across the testing blocks, BMI and sex groups. No significant difference was observed.

3.2. RT analyses - main effects

The mixed-model ANOVA revealed significant within-subject main effect for Condition ($F_{(3,\ 67)} = 16.69$; $p < 0.001$; $\eta^2 = 0.43$), but not for Task. Post-hoc tests with *Bonferroni* corrections suggested that the orthogonal conditions in both tasks consistently led to longer RT than the Baseline and Correlation conditions ($p < 0.05$). These results imply that participants experience more cognitive interferences judging PS or ED when the irrelevant dimension varies in an unpredictable direction. By contrast, when the irrelevant dimension remains constant or changes in a predictable direction, participants should judge PS and ED more quickly, due to reduced cognitive load. Test for the between-subjects effects revealed no significant main effect for both Sex and BMI.

3.3. RT analyses - two-way interaction effects

Both Sex and BMI were found to have a significant 2-way interaction with Task (Sex versus Task: $F_{(1,\ 198)} = 5.75$, $p = 0.019$; BMI versus Task: $F_{(1,198)} = 4.56$, $p = 0.037$). Post-hoc tests suggested that both sex groups performed similarly in the ED task, but the female participants took significantly longer in the PS task (M = 540, SE = 11.2) comparing to their male counterpart (M = 507, SE = 13.3). A similar pattern of results was also observed across the BMI groups. While both weight groups yielded comparable RTs for the ED task, the overweight group took significantly longer in the PS task (M = 531, SE = 12.5) than the healthy-weight group (M = 517, SE = 12.2). Delayed responses with the overweight group indicated that this group experienced increased cognitive interferences with judging PS relative to ED.

3.4. Three-way interaction effects

Furthermore, BMI group was also involved in a significant 3-way interaction with Task, and Condition ($F_{(3,\ 67)} = 4.1$, $p = 0.047$, $\eta^2 = 0.06$). Post-hoc tests with *Bonferroni* corrections were conducted to interpret the significant interaction effect. For the ED task, the two weight groups showed differential results. The healthy-weight group did not vary significantly in terms of their RTs across all conditions, whereas the overweight group took significantly longer to respond in the Orthogonal condition comparing to the Baseline conditions ($p < 0.05$), indicating the presence of the Garner Interference effect for the latter group. Conversely, for the PS task, the two weight groups performed similarly across the testing conditions – the Orthogonal condition consistently yielded longer RTs than the other three conditions ($p < 0.001$; see Fig. 3). Additionally, the RT difference between Correlation+ and Correlation-conditions was significant for the ED task with both weight groups, but not for the PS task. These results suggested that Correlation Difference (CD = Correlation- – Correlation+) was only present for the former task.

Results from the individual analyses of Garner Interference and Correlation Difference also supported findings from the group analyses.

Table 2
Summary statistics of participants in separate weight groups.

	Number (Female)	Age (SD)	BMI (SD)	DEBQ-R (SD)	Self-reported major ethnicity (%)
Healthy-weight	36 (21)	21.3 (2.2)	20.8 (1.3)	2.67 (0.71)	Asian – 22.2; New Zealand European – 66.6; Pacific Islanders and Maori – 8.3; others – 2.7
Overweight	34 (20)	21.9 (3.1)	30.0 (6.0)	2.49 (0.84)	Asian – 17.6; New Zealand European – 76.4; Pacific Islanders and Maori – 5.9; others - 0

Notes: SD-Standard Deviation; BMI-Body Mass Index; DEBQ-R – Dutch Eating Behaviour Questionnaire – Restraint eating sub-category.

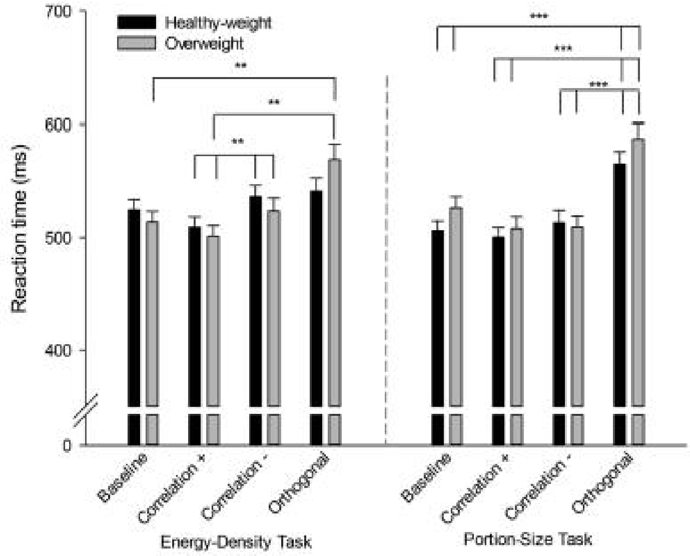

Fig. 3. Reaction time (ms) in four testing conditions for the Energy-Density and Portion-Size Task averaged within a weight group. Significant differences across testing conditions are indicated by asterisks (**$p < 0.01$; ***$p < 0.001$).

With the PS task, an almost similar number of participants in the overweight and healthy-weight group showed positive Garner Interference effects (i.e., 20 healthy-weight and 22 overweight individuals). By contrast, results from the ED task showed substantial difference between the two weight groups. Specifically, only two participants in the healthy-weight group showed positive Garner Interference effect, as opposed to 12 in the overweight group. With regards to Correlation Difference, 17 out of 70 individuals showed positive Correlation Difference for the PS task (7 being overweight), and 31 individuals showed positive Correlation Difference for the ED task (17 being overweight). Specific statistics are included in the supplementary material.

4. Discussion

Effective pre-meal planning requires an individual to accurately estimate portion size and energy density of foods. The present study aimed to test interactions between these two cognitive processes across individuals in distinct weight groups. A key finding of the study is that, in the PS task, both weight groups experienced Garner Interference effects introduced by variations of ED, indicated by increased latency in responding. That is, when making judgments concerning the PS of various food items, participants were *unable* to ignore information concerning ED. In Garner's terms, these two attributes were thus shown to be perceptually integral (Algom & Fitousi, 2016; Eidels et al., 2010; Gandolfo & Downing, 2019; Garner & Felfoldy, 1970). Intriguingly, results from the ED task varied across weight groups, with only the overweight group susceptible to Garner Interference introduced by variations of PS, whereas healthy-weight individuals were able to judge ED independently from PS. Specifically, healthy-weight participants are shown to be able to focus exclusively on ED, whereas the overweight participants when considering ED are apparently distracted by PS.

Numerous studies have previously demonstrated strong positive associations between PS and energy intake – a phenomenon termed the Portion-Size-Effect (see Steenhuis & Vermeer, 2009). However, there is very limited understanding of this link between body weight (adiposity) and portion judgements (Rolls, 2014). Detecting associations between weight status and reported PSs has been problematic in the past, perhaps due to errors of under-reporting of PS in overweight groups (Kelly et al., 2009). In empirical testing, several studies have used food photographs to assess inter-individual differences in responses to portion changes (Brunstrom, Collingwood, & Rogers, 2010; Brunstrom & Rogers, 2009; Cahayadi, Geng, Mirosa, & Peng, 2019; O'Sullivan, Alexander, Ferriday, & Brunstrom, 2010; Peng, 2017). In general, these studies suggest that people can discriminate between PSs intuitively (Brunstrom, 2011). The current findings corroborate the new data reported by Labbe et al. (2017), suggesting that PS decisions can be largely influenced by ED (measured via "perceived healthfulness" in Labbe et al. (2017)).

In addition, the current study detects evidence for differential responses across individuals. Despite overweight and healthy-weight individuals showing similar levels of accuracy, we show that the former group took significantly longer to complete the PS task. According to this finding, BMI indeed plays a moderating role in the decision-making process for PS, with the overweight group appearing relatively less sensitive to portion changes. Nevertheless, both weight groups were susceptible to interference by ED variation when judging PS, although the congruency of the PS-ED had little effect per se (i.e., small portion of low-energy-dense foods do not facilitate recognition the PS). These findings are consistent with a group of previous studies (Rolls, 2009, 2014) which highlighted that ED is of the utmost importance for food consumption, as the effect of PS on energy intake is largely determined by ED. In addition, the current finding leads to some practical implications for research in portion choice, indicating that individual judgements of PS should always be interpreted with additional consideration of ED factors. Future studies are needed to further quantify the extent of these interactions between PS and ED effect on portion choice.

Both observational and empirical studies have previously suggested that food ED is a significant factor associated with BMI (Ello-Martin, Ledikwe, & Rolls, 2005; Savage, Marini, & Birch, 2008; Vergnaud et al., 2009). For instance, Brunstrom, Jarvstad, and Rogers (2018) reported that individuals with higher adiposity were more likely to select foods with higher caloric content than individuals with healthy-weight. Also, Wang, Cakmak, and Peng (2018) reported that individuals with higher BMI showed heightened attentional bias towards high caloric food. Nevertheless, these findings are often a reflection of individual food preference, rather than the ability to discriminate ED, and there is still substantial debate about the link between weight status and ability to estimate ED. While an extensive body of research suggests that people with higher BMI are more likely to underestimate or underreport caloric value of food (Heitmann & Lissner, 1995; Larkin & Martin, 2016; Livingstone & Black, 2003), some other researchers have concluded that bodyweight is unrelated to underestimation biases (Chandon & Wansink, 2007; Wansink & Chandon, 2006). The current study found that individuals in both healthy-weight and overweight groups are able to discriminate between high versus low caloric foods with similar levels of accuracy and comparable reaction time. The key difference between these two BMI groups lies in the perception of ED in relation to PS. It was shown that healthy-weight participants were able to focus exclusively on ED, whereas the overweight participants are distracted by PS when considering ED. This finding implies that, in real-life settings, overweight individuals are more likely to underestimate ED if food is presented as small PS, and *vice versa*.

A number of recent studies have highlighted the important role of expected satiation and satiety in pre-meal planning. Individuals judge the expected satiation and satiety of food based on information learned from previous dietary experience, and then make decisions about the size of a meal (Forde, Almiron-Roig, & Brunstrom, 2015; Irvine, Brunstrom, Gee, & Rogers, 2013). The present study provided empirical evidence for the perceptual interaction between PS and ED in such situations. These interactions appear to be more consistent for overweight individuals.

Another interesting finding is that the female participants took significantly longer than male participants in the PS task, despite achieving a similar level of accuracy. This finding can be linked to a recent study by Sharp et al. (2019) which assessed male and female participants for their susceptibilities to changes in plate size, and reported differential sex responses. Specifically, male participants' responses changed significantly across plate sizes, which were interpreted as reflecting higher sensitivity to changes in contextual cues. In the present study, although the food-plate ratio was held at a constant for large and small portions, participants would have used the computer screen as an indicator for judging portion sizes. In this sense, the current study reveals findings similar to those of Sharp et al. (2019), with male participants exhibiting heightened sensitivities to portion size cues.

While the current study detects clear associations between BMI, sex and attentional biases, some potential limitations should be acknowledged. First, the cognitive task presented visual stimuli in colour instead of greyscale. Although colour is an important factor for food recognition, it can potentially introduce biases in cognitive processing speed. Such biases should, however, be alleviated by the within-subject design, and uses of multiple visual stimuli. A potential limitation of the study is that participants were not in a tightly controlled hunger state at the point of testing. While participants were asked to attend the experiment between 1400h and 1600h, with 2-h fasting, their hunger states could still potentially vary depending on their prior food intake. Future studies should implement strict controls of participant food consumption prior to experiments. In addition, as most participants in our study were students and staff members of the university, generalisation of these findings to broader populations requires further replication.

Overall, findings from the current study confirm substantial cognitive interactions when judging PS and ED, and show that these interactions are asymmetric across BMI groups. These novel observations add to our understanding of the cognitive processes underpinning individual dietary decision-making, and are potentially important for developing and improving targeted intervention strategies (e.g., attention retraining) (Yang et al., 2019). In addition, this study shows the value of cognitive tasks for investigating human eating behaviour. Notably, there is an increasing trend of using cognitive tasks, such as the Stroop and dot-probe task, for examining attentional biases in food/portion choices (Castellanos et al., 2009; Gearhardt, Treat, Hollingworth, & Corbin, 2012; Nijs, Franken, et al., 2010; Phelan et al., 2011). Importantly, these implicit cognitive methods can complement more direct measures of eating behaviour.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2019.104462.

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